Technological Performance Assessment Innovation For Elite-Level Snowboarding

A multifaceted research project focused on enhancing performance assessment in elite snowboarding by using technology. Submitted in fulfillment of the requirements of the degree of Doctor of Philosophy affiliated with the Australian Institute of Sport, the Winter Olympic Institute of Australia and Griffith University’s Centre for Wireless Monitoring and Applications.

April 20 2010

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Technological Performance Assessment Innovation For Elite-Level Snowboarding (Academic Dissertation).

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‘For Heidi’

‘Always right there with me and forever keen to roll the dice and chase wild ideas, barrels and powder’
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STATEMENT OF ORIGINALITY

"This work has not previously been submitted for a degree or diploma in any university. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made in the thesis itself."

Jason Harding (BEXSC HONS) 20th April 2010
FOREWORD

There is no right or wrong in snowboarding. Snowboarding is whatever you want it to be. It is a free sport driven by free people.

A lot of public knowledge about snowboarding has been packaged and designed for diffused mass consumption but there is a lot more to snowboarding than meets the eye. There are numerous opinions on what the sport represents and that in itself is evidence of the sport’s diversity. An opinion of what snowboarding should or should not be ought not have any bearing on how you are perceived in the industry but unfortunately it often does.

As a snowboarder and an elite-level coach I have spent the bulk of the past ten years living out of a suitcase. Snowboarding is like a drug. It is addictive. When you get hooked, your life is instantly geared toward how fast you can get back on your board and receive your next hit. It is however also a professional sporting discipline with a well established competitive arena. For the past eight years, elite level performance and the competitive side of the sport has been my primary focus. It is my opinion that for snowboarding to keep maturing as a sporting discipline, the sport needs to look after its athletes and conduct itself in a professional manner.

The majority of talented snowboarders take their sport seriously and put in a substantial amount of effort in order to make a living out of it. There are small minorities that do not take the sport seriously but as the performance levels in snowboarding continually move forward, these snowboarders quickly become mere participators, rarely pushing the boundaries of performance. There is nothing wrong with being a participator and snowboarding for recreation. My point is just that without a conscious effort, not all talented athletes succeed in the professional arena.

Given the sport attracts such a variety of individuals and therefore possess such a variety of different focuses, it is hard to name a single legend who has changed the sport in any meaningful way. If I was however to name only one person who has done this it would be Terje Håkonsen. A snowboarder in the nineties, Terje pushed the level of snowboarding in every way imaginable. Unbeatable in half-pipe, an innovator in freestyle and a back country pioneer. His vision for the future of the sport was spot-on, and he took it in that direction by way of example.
Today, it’s Shaun White and Torah Bright pushing boundaries. Over the last year, these two athletes have increased the level of men’s and women’s snowboard performance to new heights. Both athletes move seamlessly across all facets of the sport, from starring in videos and magazine shoots to garnering sponsorship on a global scale. Six months out from when this thesis went to print, there was an explosion in snowboarding performance progression, most notably with the successful introduction of the double cork by White into elite competition and Torah is arguably now the most technically advanced female snowboarder in the world.

With increased progression however comes an increased risk of injury. To learn and refine these high level tricks you require the right coaching techniques and the accessibility of safe training environments. Simply going out and renting an air bag is no guarantee of an injury free training ground. Coaches and athletes now need to treat the level of technical difficulty in these innovative tricks with respect. An athlete’s progression can not be rushed, regardless of what is at stake. World class coaching facilities and carefully constructed programs will be the key in pushing the sport for years to come.

Enter Jason Harding. He brings a unique sense of passion and enthusiasm to snowboarding. A passion that has opened my eyes and ears to innovative methods of coaching elite-level athletes and for improving the sport in general. Through the performance based projects Jason has conducted during his time with the Australian Snowboard Team (and many of these are not published in this text nor form any part of this thesis), he was able to provide coaches and the sport itself tools and technology that can guide athletes toward the elite level.

The sport of snowboarding is still very young and predominantly relies on old-school judging methods and a subjective judging system. The information in this thesis provides the reader with advanced techniques of assessing the athletic performance of freestyle snowboarders. It also provides a fresh perspective on competition judging at the elite-level. As we move forward it will be hard to judge a sport based on overall impression and personal preference. The system of micro-technology based objective measurement established through Jason’s work can only improve judging accuracy and the level of feedback provided to athletes in training and competition.

This type of research and information will be indispensable over the coming Winter Olympic quadrennial, in particular for elite level coaches, athletes and judges involved
at that level. It is not for everyone though. I have personally come across individuals within the snowboard industry who have no interest in bringing this sort of information into the sport of snowboarding. It was deemed “anti snowboarding” and “not cool” to have these sorts of concepts brought into the protocols of a sport that has a unique and often very anti-authoritarian thought processes.

The irony of the comments of these individuals however is that not long ago it would have been offensive to the sport to have private training and private half-pipes for athletes preparing for a Winter Olympic Games or any major competition. It’s for the same reason, that it is just not snowboarding. This certainly turned around in 2009-2010 however where most of the top riders and strongest teams deemed it necessary to keep their training and trick progression very secret, all in an attempt to gain advantage over international competitors.

I see the use of micro technology taking the same path as private training. Once an athlete, coach or team can see a benefit or advantage in the overall concept, then all bets will be off as to what technology is deemed “Ok” or “cool” to use by the snowboard community. After all, when it comes to Olympic medals, it is all about using the optimal training and competition preparation methods to produce elite level athletes that get out in front and win.

Ben Wordsworth, Australian National Snowboard Coach.
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... Snowboarding is anarchist punk rock focussed on a flawless aesthetic ...
ABSTRACT

This thesis focuses on the introduction of sport science and engineering techniques for performance assessment in competitive half-pipe snowboarding. Performance data was collected over three winter seasons from 2006 to 2008 including a Winter Olympic Games and was used to establish objective key performance indicators (KPI’s) that account for a large percentage of the variance in subjectively judged competition scores. These findings were then applied to customise wearable sensor technology to develop an automated performance feedback system suitable for everyday use. This system was subsequently used to run the first electronically judged half-pipe snowboard competition in the world. Furthermore, the impact of sport science and new technology on the sport of snowboarding was assessed, allowing the snowboarding community to articulate their interests in forums that convey influence. This thesis establishes that it is no longer a question of whether the theoretical framework or technological innovation is there to automatically provide objective, performance-based information for half-pipe snowboarding but rather if and how coaches, athletes and competition judges plan to utilise such capabilities. In addition, this thesis recommends that any further development and integration of such concepts be conducted in close association with core community members and be ultimately controlled from within the sport.

Video-based performance analysis was used to establish objective key performance indicators at the Burton Open Australian Half-Pipe Championships over three years (2006, 2007, and 2008), during three consecutive Fédération Internationale de Ski (FIS) World Cup (WC) competitions (throughout 2006), during the XXI Winter Olympic Games (2006) and during the Australian Institute of Sport (AIS) Micro-Tech Pipe Challenge (2007). Results showed the two independent and objective KPI’s most strongly correlated to elite-level competition success were average air time (AAT) and average degree of rotation (ADR). When AAT and ADR are combined (multiple regression, enter method) however, they explained 71 – 94%, 66 – 94%, and 80% of the shared variance in subjectively judged competition scores during the Burton Open Australian Half-Pipe Championships, FIS WC competitions, and the AIS Micro-Tech Pipe Challenge respectively. Furthermore, the magnitudes of differences in AAT and ADR between athletes achieving top three (T3) final rankings and those athletes achieving final rankings outside the top three (OT3) in the Burton Open Australian Half-Pipe Championships and the AIS Micro-Tech Pipe Challenge, and between
Finalists and Qualifiers in all three FIS WC events routinely showed moderate (ES = 0.6 – 1.2 95% CL) to very large (ES > 2.0 95% CL) effects.

Micro-Electrochemical System (MEMS) sensors and signal processing techniques can however accurately and reliably calculate objective information on half-pipe snowboarding specific KPI’s faster than video-based analysis. Signal processing based on search-based algorithms used filtered tri-axial accelerometer data to correctly identify air times associated with half-pipe snowboard acrobatics. The results displayed a very strong correlation with a video-based reference standard for air time calculation ($r = 0.78 \pm 0.08$, $p < 0.001$, $r^2 = 0.61$, SEE = 0.08, mean bias = -0.03s ± 0.02s, false positives = 0, false negatives = 0, n = 92) (value ± 95% CL). Furthermore, numerical integration of tri-axial rate gyroscope data generated a composite, dimensionless parameter termed Air Angle (AA), from which reliable classification of aerial acrobatics into four specific rotational groups (180°, 360°, 540° or 720° rotations) can be achieved. Statistically significant differences between AA across these four acrobatic groups involving increasing levels of rotational complexity ($P < 0.001$, n = 216) and the absence of overlapping measurement limits between these groups allowed recommended AA ranges to be set for reliable aerial acrobatic classification (180°, AA = 80 – 240; 360°, AA = 285 – 410; 540°, 450 – 610; 720°, 640 – 810).

This new technology was integrated into elite-level half-pipe snowboard competition during the AIS Micro-Tech Pipe Challenge on July 30th 2007. The event was designed to evaluate whether the snowboard community would embrace a competition where results were in part determined by automated objectivity and to evaluate the relationship between subjective judging and results predicted from objective information to see if prior research had ecological validity. Ten elite-level male half-pipe snowboarders were instrumented with MEMS inertial sensors throughout this competition and performance was assessed concurrently using objective information derived by technology and subjective information provided by an elite competition judge. A prediction equation using previously established weightings of AAT and ADR in combination with automatically generated, objective KPI information accounted for 74% and 82% of the shared variance in subjectively judged scores and final rankings respectively. The fact that 100% of the shared variance in subjective scores and rankings could not be explained using objective information should not be considered a weakness of this approach but a strength, as subjective assessments of style and execution should never be removed from the sport. The future of half-pipe
snowboarding competition however may be best guided a judging protocol that incorporates both objective and subjective criteria.

The capacity shown by this thesis, to automatically provide objective assessment of half-pipe snowboarding provides performance information that until this point has been unavailable. Automatically quantifying objective, sports-specific KPI’s provides an innovative solution for developing and implementing individual athlete strategy and the dependable assessment of performance in training and competition. The integration of such concepts into half-pipe snowboarding (a sport habitually focused on athletic individuality and freedom of expression) will however provide sport scientists (as implementers) and the ‘practice community’ (those affected) with challenges. The perceptions of key members of the elite half-pipe snowboard community to how emerging technology could interface with the sport were therefore evaluated using open-ended interviews and qualitative coding of subsequent data. Although there is awareness that the current focus on subjective perception of style and execution has an inability to consistently identify correct results there is also a strong and somewhat paradoxical community perception that this focus is a major strength in current performance assessment protocols. Athletes, coaches and judges are not opposed to using automatically generated, objective information in their performance assessment protocols however, there is a strong perception that further development be conducted in association with the community and ultimately controlled from within the sport.
INTRODUCTION

Once considered the pastime of social misfits and subversive, drug affected nomads reneging on adult responsibilities, snowboarding has fast become a premier Olympic sporting discipline. Upon acceptance into the Winter Olympic Games in 1998, the sport of snowboarding began as an emergent discipline in relation to other more traditional sports and since that point has been increasingly incorporated into the Olympic mold. Snowboarding however has always proudly displayed numerous intricacies of its subculture that are vastly different from existing Olympic sports and the practice community still struggle with the juxtaposition of the sport’s traditional ideals of freedom, hedonism, and rebellion and the athletic ideals of discipline, control, and continual performance enhancement. Regardless of the internal cultural divisions on what the sport should represent and perseverence of the countercultural ideology attached to snowboarding’s origins, in 2010 there was an explosion of athletic performance (lead by Shaun White, a professional snowboarder from the United States of America) in the lead up to the Winter Olympic Games in Vancouver. The subsequent scramble to emulate this level of performance by a multitude of snowboarders who would compete in Vancouver however provides evidence of the value now bestowed on Olympic snowboard competition success and elite-level performance in general.

In the current snowboarding environment, those at the elite level seem unable to detach themselves from the connotations and underlying motives associated with the term athlete, whether the expression fits the practice community’s underlying cultural ideology or not. Despite the palpable practice community divisions on how snowboarding should be perceived, and the sustained adherence by those who partake in the activity to snowboarding’s original counterculture ideology, it is important that the Olympic Movement embraces sports like snowboarding in order to maintain the relevance of its competition to the youth of today. Sports such as snowboarding however, all enter the Olympic arena having assessed performance in a subjective manner since their inception and as such, the methodology underpinning how coaches routinely assess athletic progression and how judges score competition performance is open for debate and discussion. From an Olympic competition perspective, the subjective judging protocols associated with half-pipe snowboarding are also open for manipulation and corruption and the Olympics have had problems in the past with
subjectively judged sporting disciplines (such as boxing, gymnastics, and ice skating). In light of these problems, it is largely unknown if competitive half-pipe snowboarding can indefinitely maintain its purely subjective style of performance assessment in an era when there are calls for more objectivity in judging Olympic sports.

Recent opinion has identified the need for a system of judging to be introduced that is based upon more accurate, reliable and stringent measures, with the caveat that it must do so without stifling athletic freedom of expression. In addition to these external influences, internal forces also need to be considered and this dissertation will show awareness by the snowboard community of sport’s overall self-annihilating teleology; that increased numbers of athletes ultimately achieve ‘optimal performance’, thereby outgrowing the structure of the game or competition, becoming a potential issue within half-pipe snowboarding. When this occurs, sports are then often forced to adopt altered performance assessment methods, equipment changes, or altered game rulings to again separate similarly capable athletes. It is quite possible that elite half-pipe snowboarding is not immune to this teleology. The most likely scenario would be a large number of athletes complete the most difficult aerial acrobatics with the same air times and execution levels in competition, thereby impinging on the capacity of current subjective judging criteria to reliably assess performance. Subsequently, processes need to be put into place that allow for successful integration of innovative performance assessment protocols made available by technology or other means when they become available.

Ultimately, this is where sports-science, engineering techniques, and in-depth sociological analyses come into play however, in spite of the current focus on high performance and the importance placed by the snowboarding community on Olympic competition, the sport has until recently received very little attention from scientists and their focus on objectifying sport-specific parameters in a quest to enhance athletic performance and performance assessment reliability. Although it is known that objective monitoring of athletes can enhance decisions on training progression and performance levels, in many sports objective information tailored for a specific discipline is unavailable due to lack of suitable instrumentation, which often enters the sports scene only very slowly. This dissertation was focussed purely on the provision of suitable instrumentation for the sport of half-pipe snowboarding in an attempt to negate this particular and well known issue. Within this dissertation, there is proof that there are strong, positive correlations between a number of half-pipe snowboarding specific key performance indicators and subjectively judged competition scores and furthermore,
micro-technology can be customised to automatically calculate objective information on these variables. In terms of elite-level events such as the Olympics, it is proposed that this system could provide snowboarding with an ability to remove controversial results or at least provide judges an additional tool to utilise in routine competition environments.

In many cases however, the rules associated with particular sports must be changed themselves in order to accommodate new technology and innovative concepts such as that developed and proposed within this dissertation. Furthermore, the major concern of many sporting communities is that improvements in sport science and technology such as those developed and presented in this dissertation possess a latent ability to remove the stylistic components from a sporting discipline and thereby reduce the magic of a performance to a series of mathematical equations. Hence, athletes, coaches, competition judges and the sport’s governing bodies are often reluctant to adopt new equipment and performance assessment technologies. Athletes, coaches, and competition judges therefore often need to be convinced that their cooperativeness is essential for increasing mainstream interest and performance assessment accountability in their particular sporting discipline. This issue is compounded by further complexities in half-pipe snowboarding, a sport with an underlying anarchistic and antiauthoritarian ideology, a habitual focus on athletic individuality and freedom of expression, and a community with strong views on how performance should be valued and assessed. As such, the integration of technology (whether focussed on performance assessment in training or competition) into half-pipe snowboarding will no doubt provide sports-scientists and engineers (as implementers) and the practice community (those affected) with challenges.

The most significant aspect of change in sport is that any such action can dictate the future of a sport in a way that makes reversing such changes very difficult. In this light changes, technological or otherwise, should be preceded with substantial discussion about what future is sought for a specific sport and thus, where limits might be drawn on the changes. Defining who should determine the nature of a sport ought not to be a difficult issue. It seems imperative that implementers consider and respect the personal issues of those affected and ensure practicing communities are allowed to articulate their interests in forums that convey influence. Furthermore, practice communities should be provided an element of control over the integration of any innovative concepts into their sport. Discussing and understanding the consequences of potential
rule changes made available by technology is an important aspect of any integration process and this dissertation aims to additionally provide the half-pipe snowboarding community an opportunity to not only express their opinions in forums that convey influence but also to set an example of how such process can be executed successfully within Olympic sporting cultures. The final projects associated with this dissertation were focussed on allowing key snowboard community members the opportunity to present their perceptions of how emerging technology could interface successfully with the sport.

Due to the importance and emphasis now placed on elite-level competition performances in the sport of half-pipe snowboarding and due to my personal belief that innovative sports-science and engineering techniques can improve both athletic performance and the assessment of that performance, this thesis investigated the sport itself, the aspects of snowboarding that relate well to competitive success, the capacity to customize technology for a specific sport, the methods that can allow for successful integration into elite-level competition, and finally the practice community perception of such developments. The dissertation essentially lays the foundations for a bridge between two vastly disparate cultures; one associated with sport science and its quest to enhance athletic performance and the other associated with snowboarding, a sport with an underlying anarchistic and antiauthoritarian ideology. Although undertaken with consideration of the sport’s traditional philosophies and emphasis of the practice community on the more stylistic and subjective aspects of snowboarding performance, this body of work examines the use of technology to introduce relevant, objective methods to improve athletic performance and the reliability associated with the assessment of that performance. It is important to note that any philosophical statements that occur within this dissertation without reference are based solely on my professional background as a sports-scientist and performance consultant, twenty-five years experience as a surfer and snowboarder, and my thorough understanding and personal perception of the intricacies associated with the sport of snowboarding.

In this dissertation, the manner in which objective information is collected and utilised to enhance athletic performance and improve the assessment of that performance in the sport of half-pipe snowboarding is in focus. Ultimately this dissertation introduces a performance assessment concept that although derived from principles currently used in more traditional sporting disciplines, has been tailored specifically for elite-level half-pipe snowboarding. Derived from a multitude of projects conducted in conjunction
with both national and international snowboard communities, this dissertation was ultimately designed to accomplish the following goals:

1. Establish the existence of and quantify the relationship between relevant, objective key performance indicators (KPI’s) and subjectively judged scores in elite half-pipe snowboarding competition.

2. Customise, trial and validate wearable micro-technology to automatically quantify objective information related to these sports-specific key performance indicators.

3. Integrate this automated performance assessment concept into elite-level half-pipe snowboarding competition in collaboration with the Australian snowboard community.

4. Assess the community perception and potential sociological impact of this and future integration and allow snowboarding to set an example of how such process can be executed successfully within Olympic sporting cultures.

The work in this dissertation is presented as four chapters much like a published scientific paper (Literature Review, Methods, Results, and Discussion) where for the most part, the Methods, Results, and Discussion are each split into the following sections:

1. Key Performance Indicators.

2. Sports Technology.

3. Integration Into Elite Sport.

1 LITERATURE REVIEW

1.1 The History Of Snowboarding

From an elite-level competition perspective, snowboarding is considered a relatively new sporting discipline however the ‘art’ of standing upright and sideways on a board and manoeuvring it across snow has existed since at least the 1920s (Humphries, 1996). The earliest accounts of ‘snowboarding’ report individuals riding planks of wood, sleighs and even cafeteria trays down snow covered inclines. It is difficult to detail who actually conceived the idea for the first ever snowboard. Jack Burchett however cut out a plank of plywood in 1929 and tried to secure his feet with some clothesline and horse reins. So essentially, Burchett could be considered the designer of one of the first elementary ‘snowboards’. Snowboarding’s official roots, however, came about thirty years later and can be traced to the leisure movement in the 1960s. This movement was defined by activities such as surfing, skateboarding, Frisbee throwing, hot dog skiing, and high risk activities like rock climbing and parachuting (Humphries, 1996; Popovic, 2006). Sherman Poppen, a chemical gases engineer, is the individual most often recognised with inventing the snowboard. As recalled in this interview with Flakezine Magazine (Anonymous, 1995), on Christmas Day in 1965 Poppen fixed two skis together for his daughter to "surf" down the snowy hill outside their home (Garber, 2009; Humphries, 1996; Sommer, 2005).

... Two 36 inch skis that came in a bubble pack that came at the corner drug store. They had a little leather strap over the top of them that kids could slide their shoes into. Then I put a couple of cross pieces across them about five of six inches apart. The cross pieces were actually moulding so you could put your feet up against it. Did that on Christmas day in 1965-66. Say 66, that way no one will get mad at me. They were just having a ball with them in the back yard. My wife dreamed up the name ‘Snurfer’ as a contraction of snow and surf ...

Poppen decided to patent his creation (US Patent #: 3,378,274 – Surf-Type Snow Ski – Filing Date – March 17th 1966, Issue Date, April 16th 1968) and trademarked the words ‘snurf’ and ‘Snurfer’ (US Trademark #: 1,518,101) (Garber, 2009; Poppen, 1968). He still owns the trademark to the word ‘snurf’ to this day. In 1966, Poppen licensed the product on a royalty basis to the Brunswick Corporation, a bowling ball manufacturer, and worked with them to create a board from the laminated wood used for bowling alley
gutters (Garber, 2009; Humphries, 1996). The Brunswick Corporation first marketed the board at the beginning of the 1966-1967 winter season. At $US15 the Snurfer (Figure 1) was intended primarily as a toy and sold well (over 100,000 in its first year), however in the context of the new leisure movement, the Snurfer’s potential as a significant recreational instrument was being thoroughly explored. Brunswick discontinued production of the Snurfer, but the JEM Corporation continued manufacture until the early 1980s. A rudimentary piece of equipment, Snurfer’s were infamously difficult to control because they lacked edges, bindings (now essential components of modern day snowboards), and at the time were steered by way of a hand-held rope attached to the nose of the board. These issues somewhat impeded the boards being perceived as serious recreational equipment and unsurprisingly, officially because of their uncontrollability and the associated insurance liability issues, the use of Snurfer’s were banned within the boundaries of commercial ski resorts.

**Figure 1.** Sherman Poppen is the individual most often recognised with inventing the snowboard. This image of his design was sourced from his original US Patent. He has since received recognition from the snowboarding community as the grandfather of the sport and was inducted into the Snowboarding Hall of Fame in Banff, Canada in 1995 and the Muskegon Area Sports Hall of Fame in 2001. Image: Sherman R. Poppen, US Patent 3378274, 1966.

In spite of the bans imposed on the use of Snurfer’s inside ski resort boundaries, Poppen organised the first Snurfer competition in early 1968. Racers and spectators hiked
approximately one and a half kilometres through back country snow to the competition site on a hill near Muskegon, Michigan (Sommer, 2005). This scene became more recurrent as a one by one a multitude of other commercial ski resorts around the US banned Snurfing. In order to snurf, one had to walk and the competition continued to be run until the early 1980s (Garber, 2009). It would be many years however before ski fields accepted snowboarding. The Snurfer was the precursor to the modern snowboard and the main inspiration for early pioneers to began creating more specialized and refined board designs. By 1977, Jake Burton Carpenter, an avid competitive Snurfer, began developing an improved model without a rope handle and in 1979, Burton turned up to a Snurfer contest organised by Poppen with a method of permanently attaching himself to the board. Burton was the first ever snowboarder to ride something other than the Snurfer in competition (Humphries, 1996). Although quite rudimentary at the time, his development was a defining moment in snowboarding’s history and laid the foundation for improvements in snowboard design, as recollected in this Flakezine Magazine interview with Sherman Poppen (Anonymous, 1995).

... But Jake came along in 1979, I'm reading from this article. Carpenter introduced a Burton board to a ‘Snurfer’ contest. And that's when we had a big brew ha ha. And everyone was on my boards and here he comes on a board that he'd made. Actually, it was my board, but he had made some of his own that were a little longer and wider. But he had a binding on them, so we weren't going to let them race, but there were three or four guys from Vermont, so the powers that be at the local college said, well we'll have an open division and anybody who wants can ride whatever they want. Well, his boards were very slow compared to mine, so he didn't win anything, but that was the beginning of the binding ...

The refinements of the original Snurfer board continued over the next decade and by the early eighties a number of additional snowboard brands were available. The individuals behind these improvements are the pioneers of modern snowboarding; Jake Burton Carpenter (Figure 2), Tom Sims, Chuck Barfoot and Chris Sanders. In 1985 Sims Snowboards introduced the first ever pro-model with Terry Kidwell’s signature on it. The same year, ‘Absolutely Radical’, the first magazine exclusively about snowboarding, is released (Crane, 1996, Sommer 2005, Heino, 2000). Modern competitive snowboarding began in 1981 with the first American National Titles held at the Ski Resort of Suicide Six (Vermont). The next year, the resort hosted the first international snowboard race (Howe, 1998). It was not until 1983 however that Stratton
Mountain (Vermont) became the first commercial ski resort to lift the bans imposed on the use of snowboards within resort boundaries. Others quickly followed. Skiing had attained a plateau in participant growth and snowboarding offered ski resorts a new market and the potential of enduring financial success. In the words of one cultural commentator, snowboarding was the biggest boost to the ski industry since chairlifts (Hughes 1988). Nonetheless, at this point, snowboarders comprised only six percent of the ski resort population.

**Figure 2.** Early pioneers created more specialized and refined board designs and in 1979, Jake Burton Carpenter turned up to a Snurfer contest organised by Poppen with a method of permanently attaching himself to the board without the need for a rope. Poppen recollects the moment, ‘Well, his boards were very slow compared to mine, so he didn’t win anything, but that was the beginning of the binding’. By the mid-nineties, Burton (as captured in this image) was the undisputed king of the mountain, a title he still holds today. Image: The Burton Corporation. www.Burton.com

Although the snowboard industry was regularly organising and conducting numerous individual contests up till this point, it wasn’t until 1988/1989 that snowboarding became a sport with its own international governing body ISF (International Snowboard Federation). The ISF held its first official Snowboard World Championships in Ischgl – Austria - in 1993, with competitors from the United States of America, Japan and Europe (Sommer 2005). Furthermore, it was during the early nineties that snowboarding experienced a remarkable and worldwide increase in sales, rider numbers and on-snow performance capability. During this period, large corporations organised
action sport events (for example the ESPN X-Games and Gravity Games) that included snowboarding. These events were conceived as business interests in the hope that the companies could correlate their products with the latest action sports lifestyle and the associated commercial market (Popovic, 2006). The third wave of snowboard manufacturers was raised during this time and subsequently, in the autumn of 1993, there were over fifty different companies marketing snowboards to consumers (Sommer, 2005). In 1994 ‘Ride’ Snowboards became the first snowboard specific company to be listed on the NASDAQ stock exchange (Crane, 1996). Interestingly, Poppen received recognition from the snowboarding community as the grandfather of the sport and was inducted into the Snowboarding Hall of Fame in Banff, Canada in 1995 and the Muskegon Area Sports Hall of Fame in 2001 (Garber, 2009). Throughout this period, the snowboard industry experienced rapid and exponential growth and furthermore gained significant popularity amongst society’s youth (Sommer, 2005).

A number of factors contributed to the escalating number of snowboarders and this rapid industry growth. More and more ski resorts began to open their boundaries to snowboarders, the mainstream media were reporting favourably on snowboarding, snowboarding magazines (such as International Snowboarder Magazine, Transworld Snowboarding, Snowboarder, Blunt) and films (such as Snowboarders in Exile, Critical Condition, Totally Board) communicated positive images and attitudes across the whole culture, and technological advances in equipment and manufacturing (alongside an increasingly competitive market) provided snowboarders with a wide range of cheap snowboarding equipment. Furthermore and as previously established, television and corporate sponsors were identifying the huge potential in extreme sports and ‘tapping in’ to the young male market. So much so that snowboarders themselves were also finding that they could now earn a living off doing what they love and were regularly gain notoriety and profiting from corporate sponsorship deals. Since the sport’s inchoate origin, snowboarding had become ‘the fastest growing winter sport’ (Sommer, 2005). In 1988, snowboarders made up around six percent of those actively involved in downhill snow sports, whereas skiers made up the other ninety-four percent. By 1992, snowboarders constituted twenty-four percent of those active on the slopes (TransWorld Publications, 1994) and the Snowsports Industry of America’s participation statistics showed that in 2004, half a million more snowsports visits were by snowboarders than skiers at US resorts (Hynes, 2009, Thapa, 2001).
1.2 An Underlying Counterculture

The sport of surfing was the initial influence upon the development of both skateboarding and snowboarding (Humphries, 1996). In the 1960s, surfing possessed a distinctive style, fashion, language, and media industry and furthermore propagated a lifestyle that people could adopt without experiencing the act of surfing itself. Many of the early pioneers of snowboarding identified with this lifestyle and viewed snowboarding as a winter alternative to surfing (Popovic, 2006). As a derivative of surfing, skateboarding also had a tremendous impact on the evolution of snowboarding. Skateboarding developed a direct relationship with snowboarding, especially with respect to riding style. In the 1960’s however, the general public identified those participating in these activities as social misfits and subversive, drug affected itinerants reneging on adult responsibilities (Humphries, 1996; Popovic, 2006). These negative stereotypes were derived from the perception that both surfing and skateboarding were undisciplined, hedonistic and anarchistic activities (Humphries, 1996). Whilst the social, economical and political changes occurring in the 1960’s gave youth the freedom to experiment with, investigate and question society, it also provided the opportunity for them to be dissatisfied with it (Humphries, 1996). For the most part, the public perception of the underlying ideology associated with surfing, skateboarding and snowboarding was an accurate interpretation.

Surfing, skateboarding and snowboarding were the mediums for many of society’s youth to express dissatisfaction in the sporting domain and as such, many of the participants of board-riding activities did subscribe to antiauthoritarian and counterculture values (Anderson, 1999; Heino, 2000; Humphries, 1996; Popovic, 2006). Drug use, the adoption of Eastern religions and mysticism by specific ‘soul-surfers’ (a supposed essential aid in the search for Utopia) fuelled this counterculture perception in the early 1970s and soul-surfers became ‘rotten, long haired, unwashed drug addicts’ (Humphries, 1996). Some seaside councils in the United States of America and Australia banned surfing in the mid-1960s, and this only served to widen the gap between surfers and local councils. Banning the use of the Snurfer and other snowboard equipment within the boundaries of commercial ski resorts subsequently possessed a strong social content. Many ski resort managers questioned the compatibility of snowboarding on the slopes primarily as a result of the lifestyle differences between the young & rebellious looking snowboarders and the more conservative older skiers (Heino, 2000; Humphries, 1997, Thapa, 2001).
Although surfing was the primary influence on snowboarding in the 1960’s, skateboarding had a tremendous impact on the evolution of snowboarding through the 1970’s and 1980’s and further fuelled snowboarding’s existing antiauthoritarian and counterculture ideology. During this period, members of the ‘punk’ subculture embraced the sport of skateboarding and thereby indirectly influenced the development of snowboarding. Appalled with the political failure of the counterculture movement of the 1960s that attempted to amend the social, economic, and cultural establishment, many members of the punk subculture wholly subscribed to the philosophy of Yippie leader Jerry Rubin, ‘People should do whatever the fuck they want’ (Clarke, 1976; Popovic, 2006). Whereas the previous counterculture supported universal free expression, punks encouraged individuals to strive for innovation and uniqueness in every aspect of their lives, to the extent that being socially dissimilar and offensive was enthusiastically applauded (Humphries, 2003). Skateboarders were very much exiled by society and regularly criticised as being blasphemous, degenerate, dangerous, and criminal (Grant, 1996). Popovic (2006) states that punk found solace in skateboarding because many skateboarders shared similar world views and subsequently distanced themselves intentionally from the much-despised and contaminated institutions.

Although already perceived as outcasts and suffering from institutional bans possessing an extremely strong social context, snowboarding adopted the cultural values shared by punks, surfers, and skateboarders as their own (Anderson 1999). This antiauthoritarian reputation was also partly fostered by reports of confrontations between skiers and snowboarders within commercial ski resorts. Although often exaggerated, it matched the antiestablishment image of snowboarders at a time when the sport of skiing was becoming ordered, disciplined and dull (Heino, 2000; Sommer, 2005). The antiestablishment image and the underlying antiauthoritarian ideology had become a new form of the dominant culture and additionally had become a steadfast and irredeemable public perception of participants of the sport. Sommer (2005), a former professional snowboarder and psychologist believes that it is of no surprise when you consider how the core snowboard culture was presented throughout the 1990’s. The snowboard media in many ways confirmed and continues to confirm this image via an often very narrow journalistic focus. Although the movies from the nineties had a focus on elite and cutting edge snowboarding, they often showed the more abnormal off-snow behaviours of snowboarders and industry magazines took great delight in focussing on
‘who did what at which party, who got arrested for what’ and ‘who fell asleep under the table’.

Regardless of the public perception, with each passing year, the operators of commercial ski resorts opportunistically embraced the sport’s very visible and exponential growth. Resort owners recognized the lucrative opportunities associated with snowboarding and thereby accommodated this market by creating snowboard only areas. In 1995, *Snowboard Canada* published an article entitled, ‘Build It and They Will Come’, promoting the commercial ski resorts that had constructed favourable areas for snowboarding (Popovic, 2006). Although previously considered one of the most pervasive manifestations of the nation’s outlaw culture (along with surfing and skateboarding), within the time frame of a decade snowboarders were lavishly catered to by the same industry that once ridiculed and rejected their choice of sport, lifestyle, and cultural values. This form of acceptance however came with a number of caveats. Snowboarders were forced to wear leg leashes, presumably to prevent unattached snowboards from hitting someone. With the rudimentary bindings of the early 1980s this made complete sense however, from the mid-1980s, advancements in bindings secured snowboarders to the board. Interestingly, one of the justifications for banning surfers from beaches was that riderless boards posed a danger to bathers. It was only after the development of leg ropes for surfboards that councils removed the bans. Humphries (1996) states that the compulsory leash on snowboards was and still is a form of symbolic shackling and a method to remind snowboarders that they are under constant discipline.

In the context of elite competitive snowboarding, various national and international governing bodies were established in the early nineties. These organisations however, represented a bureaucratic, regimented element of snowboarding and as such, the organisations were for the most part dismissed by a multitude of snowboarders. This obvious attempt at directing snowboarding behaviour was not well received as the majority of snowboarders were attracted to the activity for exactly the opposite reasons; that it was anti-establishment and void of rules and restrictions. A range of opinions existed at this time as to the importance of competition however, for the most part, only competitive events run by and for snowboarders were embraced by the snowboard community. Unlike other traditional sports that existed, success within snowboarding was not determined simply by the attainment of winning national and international championships (Popovic, 2006). Snowboarding’s anti-competition stance was
evidenced by the Golden Duct Tape Trophy awarded at the Mt. Baker Legendary Banked Slalom, one of the oldest and most cultish snowboarding competitions that still exists today (Heino, 2000). Duct tape was appropriated from its typical uses in manual labour jobs, patching worn work gloves and additionally snowboarders’ outerwear. Its use in snowboarding exuded ambivalence and hostility to fashion and was additionally the symbol of a well seasoned rider. The popularity of duct tape and its symbolism to the snowboarding community was further reinforced when it was ‘goldenised’ and presented as the trophy for the winner of the Mt. Baker Legendary Banked Slalom competition. The reward, purely symbolically rich as opposed to possessing any monetary value, could be interpreted as a representation of snowboarding’s ironic tension between a general contempt for competition whilst still competing in it (Heino, 2000). This tension is still evident today as elite competitive snowboarders often seem to be unmoved by competition results, maintaining an image that is part snowboarding larrikin and part professional athlete (Thorpe, 2007). Snowboarding prowess continued to be established by those within snowboarding and was typically aligned with the values and norms of core riders. Subsequently, there were significant impediments to the streamlining of the sport into one competitive discipline during this period (Popovic, 2006) and despite increasing professionalism, strong facets of snowboarding’s countercultural origins persevered (Thorpe, 2007).

1.3 Emergence Into The Olympics

The International Snowboard Federation (ISF) was formed by snowboarders in 1991, joining together a number of existing associations, becoming the global governing body of the sport, and in doing so, increasing snowboarding’s legitimacy (Humphries, 1996; Popovic, 2006). Preceding the 1994 Winter Olympic Games in Lillehammer, Norway, the International Olympic Committee (IOC) expressed an interest in having snowboarding as a cultural enrichment exhibit. There were to be no official contests, medals, or official team recognition, as the program was intended to introduce the sport as a potential Olympic event (Popovic, 2006). For various reasons, that included a lack of support by the snowboard community, the idea was dismissed. The concept of snowboarding integrating into the Olympic movement however, created a significant conflict of interest within the ISF and after the 1994 Winter Olympics had been completed, the Fédération Internationale de Ski (FIS), the ruling organisation for traditional skiing events, challenged the ISF as the global governing body of the sport of snowboarding. Snowboarders aligned with the ISF were furious with the FIS’s attempt
to control their sporting discipline. This was an obvious excise of power over snowboarding and many of the snowboarding ‘practice community’ believed the FIS were only interested in the network money and understood very little of snowboarding’s practices and underlying cultural values (Heino, 2000). Regardless, in 1995 the IOC announced that the FIS would be the governing body of snowboarding for the 1998 Winter Olympics in Nagano, Japan. Popovic (2006) references an online article titled, ‘Getting FISted’ and establishes the magnitude of outrage ISF snowboarders felt over this development with the following quote.

... The bottom line is FIS doesn’t give a lump of faeces for snowboarding, snowboarders, or snowboarding culture. They simply see snowboarding as another way to sell sponsorships, gain power, and control another winter sport. Anything they say to the contrary is a bald faced lie. They are a bunch of unethical, evil cretins set on destroying snowboarding as we know it ...

At this point, allegiances were formed within the snowboarding community and were divided between the snowboard controlled organisation and the skiing based international governing body that now controlled the entry portal for snowboarders wishing to compete at the Winter Olympic Games. Sommer (2005) states the reason for such division was partly because the riders weren’t ready for regimented and stratified ideals represented by the Olympic movement and partly because the general public and the IOC was not ready for the snowboarders’ rebellious lifestyle. One of the most significant events in snowboarding history was when Terje Hâkonsen of Norway decided, in a loud and very public manner, not to compete in the Winter Olympic Games in Nagano. (Humphries, 1996; Popovic, 2006; Sommer, 2005). At the time Hâkonsen was widely regarded as the best snowboarder in the world and he firmly believed (and still does) that the Olympic movement misrepresented snowboarding, that the IOC were comprised a group of Mafia like officials, and that the event itself was tantamount to joining the army (Heino, 2000; Popovic, 2006).

... When I say the mafia, I mean what most people say in the word, people who take over control but never let anyone have an inside look at what they are doing ...

The division of opinion within the snowboarding community pertaining to the inclusion of snowboarding into the Olympic movement was basically a result of resistance to the discipline of bureaucracy and power (Heino, 2000). For the most part discipline is a corrective action and snowboarders saw no reason for their current underlying ideology
to be corrected. Regardless, upon acceptance into the Olympic Games in 1998, the sport of snowboarding began as an emergent activity in relation to the other more traditional events and was incorporated increasingly into the Olympic mold (Popovic, 2006). Immediately, the IOC began disciplining its new sport so it could be successfully included in the Olympics and the most famous example of this is when the governing body stripped snowboarding’s first ever Olympic gold medallist, Ross Regliabati, of his gold medal because he tested positive to marijuana. Questions arose to the justification of stripping a sporting medal from an athlete for positive traces of a drug that would more than likely hinder his performance than enhance it. The FIS however had not banned marijuana specifically for giant slalom snowboarding (the event that Regliabati won) and the medal and the result were therefore reinstated but not without tarnish for himself or the sport (Heino, 2000). Despite these consequences, and although snowboarding proudly displayed numerous intricacies of the subculture that were vastly different from already existing Olympic sporting disciplines, they had begun to shift to more traditional patterns with inherent formalised rules, organisational control, and guidelines regarding what is acceptable behaviour (Popovic, 2006).

Håkonsen however refused to be turned into a uniform wearing, flag bearing, and walking logo and set about devising his own competitive snowboarding circuit that would hold true to snowboarding’s alternative spirit. In 2002 he partnered industry figures to create a rival organisation, the Ticket To Ride World Snowboard Tour (TTR), in an attempt to gain autonomy for a sport that many believed was at the time being treated as a ward of skiing (Higgins, 2009). To this day, the TTR acts as an umbrella organisation for 185 independent snowboard competitions and awards a men’s and women’s world champion at the end of the season. The TTR has been positioned as a rider-driven organisation (Higgins, 2009) and has always maintained the emphasis on competitive events run by and for snowboarders that was embraced wholeheartedly by the snowboard community in the early nineties. Snowboarding therefore is currently divided into two competing sanctioning bodies. One is governed by the FIS which holds the World Cup competition and entry pathway to the Winter Olympics and the other is governed by the TTR which maintains the rider focussed aspect of snowboarding’s ideology. Interestingly, athlete results and rankings achieved on the TTR World Snowboard Tour arguably garner more respect in snowboard communities than those achieved on the FIS sanctioned World Cup and Winter Olympic competitions. Cultural shifts however brought about by the continual emergence of snowboarding as an elite-
level and premier Olympic discipline have slowly become increasingly normalised and accepted by those in the snowboarding community (Popovic, 2006).

Even though prowess within the snowboarding community continues to be defined by core members, the general consensus towards participation in, and acceptance of, the Olympics has become the norm. Although Popovic (2006) concludes that many of snowboarding’s conflicting values and countercultural actions have been either limited or absorbed by the dominant system of Olympic sporting ideology, there is still strong evidence of snowboarding’s antiauthoritarian origin. Sommer (2005) states that the riders committed to the FIS governed World Cup and Winter Olympic competitions are moving away from the typical snowboard lifestyle, with a focus on training, diet and preparation protocols that are normally the realm of athletes competing in more traditional sports. Riders like Shaun White (two-time Olympic Games Half-Pipe Gold Medallist) however have embraced the opportunity to partake in the Games and reaped the benefits of popularity, exposure, and sponsorship from any associated success (Popovic, 2006). White however routinely downplays the increasing aspects of professionalism in snowboarding in an interview with Rolling Stone (Edwards, 2006).

... We are still the dirty ones in the bunch, the sketchy snowboard kids. I don’t think I’d have it any other way ...

Of course, neither would the corporate sponsors who have profited enormously from the commodification of snowboarding’s perceived irresponsible and uncontrolled image (Humphries, 2003; Thorpe, 2007). Regardless of cultural divisions on what the sport should represent and the perseverance of the antiauthoritarian and countercultural ideology attached to snowboarding’s origins, in 2010 there was an explosion of athletic performance (lead by White) in the lead up to the Winter Olympic Games in Vancouver. The subsequent scramble to emulate this level of performance by a multitude of snowboarders who would compete at in Vancouver provides evidence of the value now bestowed on Olympic snowboard competition success and elite-level performance in general. In the current snowboarding environment, those at the elite level seem unable (however hard they try) to detach themselves from the connotations and underlying motives associated with the term athlete, whether the expression fits the practice community’s underlying cultural ideology or not. This thesis is subsequently focussed solely on elite snowboarding (regardless of which governing body, if any it has been performed under) and examines techniques to improve athletic performance of
future snowboard athletes and additionally the reliability associated with the assessment of their performance in competition.

1.4 Half-Pipe Snowboarding Defined

The sport of snowboarding is currently juxtaposed between its traditional ideals of freedom, hedonism and rebellion and the athletic ideals of discipline, control, and continual performance enhancement. Although this thesis has been undertaken with consideration of the sport’s traditional ideologies and emphasis of the ‘practice community’ on the more stylistic aspects of snowboarding, it is focused purely on objective methods to improve elite athletic performance and competition judging reliability in half-pipe snowboarding. Half-pipe snowboarding is now an established discipline of snowboarding and consists of an athlete performing a series of aerial acrobatic manoeuvres on a special course made of snow. The discipline made its Olympic debut during the 1998 Winter Olympic Games in Nagano, Japan. Skateboarding’s influence on snowboarding is strongly evidenced within the discipline of half-pipe snowboarding. The half pipe, literally the bottom half of a large pipe, was a popular piece of skateboarding equipment and snowboarding pioneer Tom Sims integrated the concept into snowboarding by building the world’s first snowboard half pipe in 1983 (Humphries, 1997).

The current half-pipe courses are shaped like long half cylinders and are usually created from large amounts of snow shaped into the preferred profile using specially designed snow groomers. Although dimensions vary, elite competition half-pipes are commonly 160 – 200m long, 18m wide, have wall transitions of 7 - 8m (22ft) and are situated on an inclination of approximately 18 degrees (Figure 3). The courses can now be totally man made; utilising steel framing, synthetic grass, and artificial snow however most are still routinely created by grooming natural snow into the preferred profile. Snowboarders gain speed on the half-pipe transitions in order to come up over the lip (rim) of the half-pipe and perform acrobatic aerial tricks. The objective in recreational and competitive half-pipe snowboarding is to perform well executed and stylish routines consisting of complex aerial acrobatic manoeuvres that are executed as high above the half-pipe lip as possible. The sport provides a competitive platform allowing individuality and athletic freedom of expression and the routines are currently judged in competition by a subjective measure termed overall impression (OI). OI takes into account a number of sport specific components such as the amplitude, degree of
rotation, difficulty, style and execution, the sequence and combination of manoeuvres, the amount of risk in the routine, the use of the half-pipe including the line taken and how a run progresses and flows (FIS Snowboard Judges Manual, 2008/2009).

**Figure 3.** Fédération Internationale de Ski (FIS) World Cup Half-Pipe Snowboard Competition, Leysin Switzerland, 18th January 2006. Image: Jason Harding.

Judging is normally conducted by a team of professional snowboard judges using this subjective measure. Routinely there are five judges with one additional Head Judge. The Head Judge’s role is to oversee and maintain the reliability of the judging process. The Head Judge does not contribute an individual score to any performance. Each of the five judges scores individual competition performances out of a maximum of ten. All judge’s scores (except for the Head Judge’s score) are then combined for each run generating a total score with a maximum value of fifty points. Competitions are usually conducted using a qualification and a finals round. In the qualification round, athletes are provided the opportunity to complete two runs. The run associated with the highest judged score for each athlete is used to determine competition rankings and a set number (usually twelve) of the best performing athletes in the qualifications round move into the finals. These athletes (Finalists) are again provided the opportunity to complete two runs with the highest judged score for each athlete used to determine competition final rankings.
1.5 Sports-Science And Athletic Performance

Put simply, sports-science is concerned with providing either prospective or retrospective evidence that improves sports performance (Bishop et al., 2006) and often, as in the case of this thesis, sports performance assessment. The most common sports-science research is ‘basic research’ that is predominantly performed by academics, usually published and may or may not have application in elite sport. ‘Applied research’ is primarily focussed on the production of an outcome that is relevant to a particular sport or can be applied to enhance performance or reduce injury incidence (Gabbett, 2006). Sports-science utilised to enhance athletic performance extends beyond mainstream sciences and encompasses an interdisciplinary and multidisciplinary approach (Nevill, 2008). For example, the Sports-Science and Sport Medicine Department (SSSM) at the Australian Institute of Sport (AIS) is comprised of experts in the fields of physiology, biomechanics, performance analysis, nutrition, physiotherapy, psychology, sports medicine, technology, data analysis, and statistics working in close association with elite-level athletes, coaches and team support staff in order to improve performance. Applied sports-science is now routinely used to enhance the performance of elite-level athletes in a multitude of sporting disciplines.

Nevertheless Bishop et al. (2006) questions the contribution of sports-science to athletic performance. In an analysis of articles published in six leading basic science journals (25 000 articles), it was reported that only two percent contained some claim to future applicability in their respective fields. Bishop et al. (2006) reasons that if the frequency of successful translation into application were to be underestimated by 10-fold, these findings would strongly suggest that transfer rate of basic research into practice is very low. Although a similar study has not been conducted with respect to sports-science research, it is likely that the conclusions would be similar. While sports-science research need not be immediately relevant, if it is to be considered applied, should possess the capacity to realistically intervene and enhance current athletic performance and performance assessment protocols (Farrow, 2006; Gabbett, 2006; Newton, 2006; Bishop et al., 2006). Valuable, applied sports-science research therefore should involve a three step process. First, a robust relationship needs to be formed between a sporting disciplines key stakeholders (i.e. coaches, athletes, administrators, organisations) and scientists before potentially relevant research topics can be indentified and accepted. Second, upon the identification of a research focus, the sport scientist must be able to clearly state what the project will involve for it to be successfully executed. Finally,
once a research project is completed, the results need to be articulated to stakeholders so that the outcomes and applicability can be understood by all (Farrow, 2006).

The bulk of sports-science research conducted specifically with snowboarding has attempted to quantify different aspects of injury associated with snowboarding, and most of these reports focus on recreational athletes participating in general snowboarding activities (Bladin et al., 2004; Hagel et al., 2001; Idzikowski et al., 2000; Levy & Smith, 2000; Machold et al., 2000; Nakaguchi et al., 1999; Pino & Colville, 1989; Prall et al., 1995; Ronning et al., 2001; Torjussen & Bahr, 2005; Yamakawa et al., 2001; Young & Niedfeldt, 1999). Unlike more traditional sports such as swimming, running, cycling, and gymnastics, very little is known about the characteristics of snowboarding’s best athletes or the demands of elite-level competition. The high performance aspects of elite-level half-pipe snowboarding training and competition (Figure 4) however have not been addressed sufficiently in the scientific literature. Kripp, (1998) did publish the results of one project focussed on the physiological demands associated with half-pipe snowboarding. The conclusions however were based on a low number of trials with only three subjects training on a half-pipe too small and short to be representative of current courses and subsequently, the results would now be considered irrelevant to elite snowboarding performance.

Like other sports that rely on subjective performance assessment however, the methodology underpinning how coaches routinely assess athletic progression and judges score competitions is open for debate, discussion and improvement. The reliance on subjective performance assessment in half-pipe coaching, athlete preparation techniques, and competition analysis currently fails to capitalise on the benefits of information that can be derived using an objective sport science approach. Furthermore, from an elite-level competition judging perspective, the current reliance on subjectivity to assess athletic performance is an open door for potential bias and corruption at the elite-level. Although, snowboarding continues to retain its countercultural identity there is now a strong focus on achieving a high level of performance, as noted by this comment from a young professional snowboarder (Anderson, 1999).

... I guess it's kind of like controlled chaos. Controlled anarchy with a cause behind it. The cause is to go bigger and fatter than everybody, or spin the most or whatever you're doing at the time. And you want to do it better than everybody else ...
In the context of this thesis, a targeted sport science approach has the potential to enhance performance assessment techniques for half-pipe snowboarding in both training and competition environments, with the potential to improve athletic performance and judging reliability. This thesis therefore focuses on a valuable introduction of applicable and action based sport science, performance analysis, and engineering techniques, targeting enhanced performance assessment in half-pipe snowboarding. It is proposed that this focus can provide a wealth of augmented feedback opportunities for the sport that are currently unavailable.

![Image of snowboarders performing aerial tricks on a half-pipe]

**Figure 4.** Snowboarders gain speed on the half-pipe transitions in order to come up over the lip (rim) of the half-pipe and perform acrobatic aerial tricks. The objective in recreational and competitive half-pipe snowboarding is to perform well executed and stylistic routines consisting of complex aerial acrobatic manoeuvres that are executed as high above the half-pipe lip as possible. The high performance aspects of elite-level half-pipe snowboarding training and competition however have not been addressed in the scientific literature. Professional snowboarder competing at the Burton Open Australian Half-Pipe Championships. Perisher Valley, Australia 2008. Image: Heidi Barbay.

Feedback is important in all aspects of motor behaviour as it is essentially our brain’s link to the body and to the environment (Shea & Wulf, 1999). The importance of feedback in the development of motor skills and the interest in research pertaining to this field was established in the 1950’s (Bilodeau et al., 1961). Documented as the single most important performance enhancing variable, second only to actual training and repeated practice, feedback is a critical part of the overall coaching process (Drawer & Sidall, 2004; Schmidt & Lee, 1999). Feedback is essentially defined as ‘sensory
information resulting from the performance of the individual’s movements (Schmidt & Lee, 1999). Feedback in its most rudimentary form is therefore essentially an intrinsic process of proprioceptive awareness and ‘feel’ requiring no external source of information. Augmented feedback however is a sub-section of feedback and is described as ‘information about performing a skill that is added to sensory feedback and comes from a source external to the person performing the skill’ (Magill, 1997). The addition of accurate and reliable augmented feedback is a key contributing factor to improving athletic performance as it enhances ‘perceptual representation and retention of modelled activities’ and has positive effects on individuals as they attempt to acquire or perform motor skill (Jannell et al., 2003; Kirby, 2009; Magill, 1997; Mononen et al., 2003). It has therefore fast become a fundamental aspect of athlete training, elite, amateur, or recreational, to enhance athletic performance (Anderson & Collins 2004).

It is questionable whether subjectively derived augmented feedback protocols (utilised by coaches worldwide and the current form of augmented feedback provided to snowboard athletes) have any significant performance benefit. There is no scientific literature explaining whether or not subjectively acquired, coach driven subjective feedback is superior over absolutely no feedback at all. There is however, evidence that reveals that coaching observation and recall is flawed without the assistance from some form of performance analysis technology or strategy, and that only 30-40% of relevant performance information is accurately recalled post sporting event (Franks 1983; Franks and Miller 1986). Knudson and Morrison (1997) state the reason for this seems to be the limitations of human mechanisms which capture, store, and recall pertinent information. Therefore it would seem that subjectively derived feedback is most probably incomplete and possibly inaccurate, and it is more than likely that such information could negatively influence the impact of coaching interventions, having the possible effect of stifling athlete development. Subsequently, there is a need for more accurate and reliable information derived from the environment in which athletes routinely train and compete so that coaches and judges may provide superior augmented feedback with the capacity to enhance athletic performance and competition judging reliability respectively.

One approach is to obtain quantitative information that is practically relevant to performance, a ‘performance indicator’. A performance indicator is a selection or combination or action variables that aims to define some or all aspects of a performance (Hughes & Bartlett, 2002). To be useful in an elite sporting context, a performance
indicator should relate strongly to successful performance outcomes. Hughes & Bartlett (2002) state that biomechanical performance indicators are often linked to the outcome via hierarchical models in which a clear biomechanical relationship exists between each of level of the model (also evidenced with mathematical modelling) which often serves to reinforce this relationship, particularly in closed skills. For example, a mathematical modelling publication by Best et al., (1995) provides evidence of the optimal combination of two javelin throw release parameters (performance indicators) where even small departures from the optimal release angle of attack and release angle result in a decrement of performance. Sport scientists and coaches can use performance indicators to assess the performance of an individual or team. They are often used in a comparative manner (i.e. against competitors, or specific groups) and can additionally be used in isolation as a measure of intra-athlete / team performance (Hughes & Bartlett, 2002). Athletic performance assessment conducted by sport scientists in this manner is now routinely transferred out of the laboratory in order to obtain information as it occurs in the field (Lyons, 2005) but until now, there has been no available scientific data associated with the relationships between objective performance indicators and successful competition outcomes for half-pipe snowboarding.

There are numerous sporting disciplines that are based primarily on aerial acrobatic skill and therefore have relevance to snowboarding that have been associated with performance analysis research. A video based performance analysis of elite spring board divers has demonstrated that airtime contributes to the ability to perform more complex twisting dives (Sanders & Burnett, 2004). Similarly, gymnastics performance models have been developed that identify how important take off velocity is for achieving airtime and the rotation required to perform a triple back summersault when tumbling (King & Yeadon, 2004). Of particular interest is the study performed by Takei et al. (2003), who examined the top 16 and lowest 16 performers in the vault at the 2000 Olympic Games. The experimental design used in this study allowed researchers to identify many important aspects of the gymnastics vault that could be improved in developing athletes who are competing at the highest level but not winning. Takei et al. (1996) has also successfully used this experimental design to understand how the best gymnasts differ from other good but lesser successful gymnasts performing tricks on the parallel bars. Success or failure in a performance is relative, either to the opposition or to previous performances of a team or in the context of half-pipe snowboarding, an individual (Hughes & Bartlett, 2002). It is proposed that a
performance analysis approach taken with the sporting discipline of half-pipe snowboarding could elucidate the differences between elite and sub-elite level athletes, the differences between varying levels of performance within an elite-level population, and additionally provide quantitative insight into the technical skill requirements for competition success at the elite-level. Although there is a community perception that air-time (AT) and degree of rotation (DR) have an impact on half-pipe snowboard competition success, the combinations of these variables, the amount of shared variance they explain in competition scores and the exact magnitudes of differences in AT and DR between athletes who succeed in competition and those that do not however, can only ever be determined objectively. Laboratory based objective performance assessment of half-pipe snowboarding (and snowboarding in general) is currently impossible. As is the case with a multitude of other sporting disciplines, the pursuit of ecologically valid field-based data is now prioritising performance assessment, notwithstanding the difficulties presented in this approach (Lyons, 2005; Fuss, 2008).

Although accurate and reliable feedback can improve athletic performance and provide a basis for developing and implementing individual athlete strategy, dependable assessment of performance progression, and team selection criteria, it must be provided in a timely manner to be valuable in both a training and competition performance assessment environment (Kirby, 2009; Fuss, 2008). For an augmented feedback system to be considered valuable in an elite sporting environment, it must possess the capacity to significantly contribute to the shortening of data acquisition time according to the principle of objectively supplementing rapid and immediate information (Müller et al., 2007). Performance technologies can now allow innovative ways of presenting or imparting performance information, stimulating the athlete and coaching directions, the training and competition environment, and enhancing the learning process (Drawer and Sidall 2004). The provision of augmented feedback in an elite athletic context broadens the notion of technology to include the whole system of knowledge application, surveillance, and evaluation techniques that improve performance (Miah & Mitchum, 2005). Current methods of providing feedback on technique however are largely based on data logging and video based systems (Anderson and Collins 2004). There is a large amount of literature related to the effectiveness of video feedback (Guadagnoli et al., 2002; Liebermann et al., 2002) although in terms of elite-level athlete augmented feedback, the disadvantages are the lack of real time relay of this information and the lack of quantitative data (Anderson & Collins, 2004). There are a number of video
based systems that allow the provision of quantitative data however, the time delay in post processing of this information is an issue and hence there is a non-immediate nature associated to it which may limit its effectiveness as an augmented feedback tool. Anderson & Collins, (2004) have shown evidence of the effectiveness of technology driven, quantitative, augmented feedback on rowing movement consistency and stress the immediacy of the data presented to an athlete is vital to gain maximal benefit from augmented feedback. There are real time video based systems that provide quantitative data however, the information provided may not be truly instantaneous and are therefore termed ‘pseudo real time information feedback’ (Anderson & Collins, 2004). Whether it is the cost of utilising a near real-time video analysis system, the labour intensive nature of more widely used video based analysis systems, they all pose problems for elite-level athlete support and feedback and coaches, athletes, and sport scientists are currently searching for a better alternative.

1.6 Technology And Athletic Performance

Advances in information technology have made it possible to augment and improve the feedback coaches and athletes can access during training and competition in a multitude of sports. Furthermore, modern technology has had such a profound impact on sport that many athletes and coaches now consider information derived from technological advances as an invaluable resource (Liebermann et al., 2002). This however is not the case within the sporting discipline of half-pipe snowboarding. Coaches, athletes and competition judges still rely on subjective performance assessment and for the most part, are unaware of the benefits an objective approach could provide. There is also a lack of instrumentation, which in general enters the sport scene very slowly (Fuss, 2008) however in the case of half-pipe snowboarding, there also is a very limited amount of technology specifically designed to quantify important facets of the sport. Although the sport is well placed to take advantage of this shift in performance assessment ideology, half-pipe snowboarding is also at the mercy of those developing field based quantification methods to generate a product tailored specifically for the sport. There have been many attempts to develop or use advances in technology to objectively quantify specific aspects of snowboarding in the field however, instrumentation imbedded in equipment or worn by athletes is often impeded by the size and mass of specific sensors which require power supplies, transmitters, receivers, storage devices, and the necessity to be attached to the athlete’s body (James, 2006; Knoll, 2006; Sands, 2008). Both situations remove any possibility of monitoring
snowboard performance without restricting or altering some aspect of an athlete’s movement. Of those that have minimised both weight and tethering, very few focussed on generating data directly associated with elite half-pipe snowboarding performance such as that promoted within this study.

Researchers for example have documented the use of an electromagnetic tracking system (FASTRAK, Polhemus) to quantify the kinematics and kinetics (angular displacement and joint moment torques) related to snowboard turns (Doki et al., 2005). Using this electromagnetic tracking system, objective information pertaining to angular displacement and joint moment torque information related to snowboard turns can be quantified upon post processing of data captured on-snow. The same electromagnetic tracking system was also utilised by another group of researchers who were able to provide quantitative data on the degree of dorsiflexion, eversion and external rotation of the ankle joint complex during on-snow trials of two types of snowboard boots (Delorme & Tavoularis, 2003). By utilising the ability to assess quantitative data captured in the field it was shown that ‘step-in’ snowboard boots (which are stiffer than regular snowboard boots) allow less dorsiflexion, eversion and external rotation than softer boots, thereby providing quantitative evidence as to why ‘step-in’ boots are associated with a lower rate of fractures of the talus than softer boots. The development and associated integration of a dynamometric platform focussed upon field based load data acquisition in snowboarding has also been presented (Bianchi et al., 2004). This dynamometric device is able to measure all load components transmitted between the boots and snowboard bindings without interfering with current snowboard binding technology. This platform has the capacity to provide quantitative information on the forces and torques (in 10 directions) imparted by the snowboard boot onto the bindings. On-snow field tests utilising this device showed that positive forces are witnessed at the front of the binding plate during a front-side turn and negative forces are witnessed at the front of the bindings in a back side turn.

Furthermore McAlpine & Kersting (2006) conducted an initial ‘on-snow’ trial and validation of a similar snowboard mounted force platform designed to fit beneath the bindings of any standard snowboard. The aim was to detail the biomechanical aspects of snowboard jump landings and assess the loads applied to the lower limb of a snowboarder upon landing. The complete prototype measured 40 mm thick and had a mass of 2 kg. Pilot testing of this system showed that there is substantial ankle joint loading during jump landing situations with the capacity to cause injury. Krüger &
Edelmann-Nusser (2009) developed an inertial measurement suit and used it in combination with a bilateral insole measurement system to collect data on freestyle snowboarding in the field. The system consisted of 16 sensor units and two transmission units. The sensor units include gyroscopes, accelerometers, as well as magnet field sensors were placed in a suit worn by the snowboarder. Data loggers used to store data were carried by the snowboarder in a backpack. The sensor units were fixed to the boots, lower legs, upper legs, pelvis, shoulders, head, upper arms, forearms, and hands of the test person. ADGPS system was additionally employed (attached to the snowboarders helmet) to determine absolute position of the snowboarder in space. Ranges of movement of the ankle joint, forces essential to perform snowboarding manoeuvres were measured, and the combinations of joint angles and landing forces occurring during the landing phase of aerial manoeuvres were found to have the potential to cause injuries.

The interpretation of information provided by technological advances into something relevant for use by coaches and athletes should additionally constitute a large component of any research focus. Research that developed and utilised a dynamometric platform (Bianchi et al., 2004) stated that knowledge of load histories in snowboarding will allow a deeper insight into rider’s motion dynamics during carves or jumps. Field tests utilising this device showed that positive forces are witnessed at the front of the binding plate during a front-side turn and negative forces are witnessed at the front of the bindings in a back side turn. The ability to measure forces accurately and reliably are academically sound and do provide quantitative insight into a rider’s motion dynamics during carves or jumps however, the declaration that this information will help coaches and athletes in functional evaluation and training monitoring is optimistic. The conclusions that force is generated on the front of the binding during a front-side turn and not generated on the front of the binding during a back-side turn (it is shifted to the heel of the binding) is common knowledge to all those who snowboard, and as such seems to offer relatively limited insight to elite-level performance diagnostics and competition preparation. It is believed that the development and validation of this novel technological monitoring device, has been conducted with the utmost scientific rigour and has the potential to generate invaluable information of relevance to elite-level coaches and athletes. The research and line of enquiry however, seems to have occurred independently of key stakeholders and there is no evidence of the initiation or
maintenance of a partnership with elite-level coaches and athletes required for successful integration of this concept.

Excess weight, tether and unnecessary equipment are additional issues for sport scientists and engineers attempting to practically apply technology to elite-level sporting environments. The primary issue is that it removes the possibility of monitoring athletic performance in its natural state. Although accuracy and reliability of measurements are extremely important aspects of technology based in-field monitoring, the benefit of such scientific rigour is lost if athletes alter their performance and movement patterns as a result of this scientific scrutiny. The electromagnetic tracking system used by Doki et al., 2005 and Delorme & Tavoularis, 2003 to quantify angular displacement and joint moment torques and the degree of dorsiflexion, eversion and external rotation of the ankle joint complex related to snowboard turns upon post processing of data captured on-snow respectively was a worthwhile goal and exemplifies current field based performance assessment ideologies. The bulky electromagnetic tracking system worn by the subject and the ten kilogram measurement system carried by the researcher tethered to the subject however, is far from the unobtrusive measurement systems this shift in ideology is targeting. The initial findings from the snowboard mounted force platform (SFP) developed and trialled by McAlpine & Kersting, 2006 and the inertial measurement suit developed and trialled by Krüger & Edelmann-Nusser (2009) have valuable and practical implications for injury prevention in snowboarding however, even a system with a total weight of 2kg (such as the weight associated with the force platform used by McAlpine & Kersting, 2006) has an enormous potential to restrict or alter movement, in particular removing the possibility of assessing elite-level performance. Furthermore, the difficulty of using the inertial measurement suit (Figure 5) developed and trialled by Krüger & Edelmann-Nusser, (2009) was evidenced by their published ‘on-snow’ trials providing performance results from only one test-run by an experienced recreational snowboarder. Monitoring systems requiring the use of heavy equipment and tethering devices constrict and alter normal athletic movement patterns, thereby removing any relevance to real life snowboarding technique. These systems would most likely prevent any data collection from elite-level athletes training or competing in aerial acrobatic events with elements of risk involved, such as half-pipe snowboarding.
Figure 5. Excess weight, tether and unnecessary equipment (as shown in this image) remove the possibility of monitoring athletic performance in its natural state, making technologically based performance assessment of elite-level athletes in training and competition virtually impossible. Image: Krüger & Edelmann-Nusser, (2009).

The advancements in micro-technologies such as tri-axial accelerometers, tri-axial rate gyroscopes, tri-axial magnetometers and other technologies however mean it is now possible to build instrumentation small and unobtrusive enough for a number of field-based applications. The capacity of inertial sensors to accurately measure human motion thousands of times per second in multiple axes and at multiple points on the body is well established and on-board data storage negates the need for equipment tethering (James, 2006). Inertial sensors respond to minute changes in inertia in the linear and radial directions and are known as accelerometers and rate gyroscopes respectively. (James et al., 2009). The basic mechanism underlying inertial measurement is often described in terms of a mass-spring system, which operates under the principle of Hooke’s Law \( F = kx \) and Newton’s 2\textsuperscript{nd} law of motion \( F = ma \) (Kavanagh & Menz, 2008). When a mass-spring system experiences compression or stretching forces due to movement, the spring produces a restoring force proportional to the amount of compression or stretch. The stiffness of the spring and the mass can be controlled and therefore the resultant acceleration of the mass element can be determined from characteristics of its displacement. The displacement of the mass element can be explained because as the mass element in an accelerometer reacts to
movement; the compressive restoring force of the spring is exerted onto a piezoelectric material which in turn elicits a surface charge proportional to the compressive force. The relationship between the output of an inertial sensor and a corresponding reference value is determined by 2-point calibration procedures aligning axes of sensitivity with and against the direction of gravity (Green & Krakauer, 2003; Kavanagh & Menz, 2008).

Accelerometers measure linear acceleration at the location of the sensor itself, typically in one or more axes. Rate gyroscopes measure angular acceleration or angular rate (how quickly an object turns) around a single axis (Green & Krakauer, 2003; James et al., 2006). The rotation is typically measured in reference to one of three axes; yaw, pitch, or roll. An accelerometer or rate gyroscope with one axis of sensitivity can be used to measure other axes by mounting the rate gyroscope differently (i.e., aligning with a different orthogonal axis or just by mounting it on its side). Current inertial sensors are millimetres in size (~5mm²) and can be packaged together orthogonally subsequently providing multi-axial inertial assessment (James et al., 2009; Weinberg, 1999). In recent years, inertial sensors have become widely available at low cost, due in large part to the adoption of the technology by industry such as the automobile industry where they are deployed in car airbag systems (accelerometers) and automatic, differential braking systems (rate gyroscopes) (Green & Krakauer, 2003; James et al., 2009; Weinberg, 1999). The use of inertial sensors to measure activity in sport (Montoye et al., 1983) and gait analysis (Kavanagh et al., 2005; Mayagoitia et al., 2002; Moe-Nilsen & Helbostad, 2004) has been prevalent in biomechanical analysis of both the sport and health industries. Moreover, the application of inertial sensors will continue to increase as advancements in portable computing, storage and battery power become available (James et al., 2009). By customizing these technological advancements, there is enormous potential for in-field quantification of information for sport without the problems associated with size, weight and the necessity for athlete tethering (James et al., 2009; Fuss, 2008).

As an example of micro-technology’s potential in monitoring athletic performance, miniature inertial sensors (containing varying combinations of tri-axial accelerometers, tri-axial rate gyroscopes, tri-axial magnetometers, and GPS technology) housed within small battery powered units (often attached to an athlete at the sacrum as close as possible to the Centre of Mass) have been used to measure the energy expenditure during running (Wixted et al., 2007; Wong, et al., 1981), determine the rotational
kinematics of the lower leg during sprint running (Channels et al., 2006) characterise different strokes (freestyle, breaststroke, backstroke, and butterfly) and accurately measure lap times in elite-level swimming (Davey et al., 2005; Davey et al., 2008), quantify the translational and rotational motion of the tennis swing (Ahmadi et al., 2006), provide real time boat velocity, stroke diagnosis (catch and release, rate), degree of boat yaw, pitch and roll, and spectator immersion in elite-level rowing (Mackintosh et al., Lai et al., 2003), quantify bowling run up length, bowling run up speed, and degree of hip rotation upon post processing of data collected during the bowling action in cricket (Rowlands et al., 2009), analyse the biomechanical properties of cricket batting technique (Busch & James, 2007), provide comprehensive and validated information pertaining to match analysis and subsequent physiological demand in elite-level soccer, (Hewitt et al., 2007; Morten et al., 2010), quantify a vast amount of biomechanical components associated with golf (Ghasemzadeh et al., 2009), specifically measure deceleration and uncock timing in the golf swing (Ohgi, et al., 2005), and develop a wireless sensor based system of scoring for boxing and combative sports (Partridge et al., 2005).

In the context of winter sport, researchers have recently used inertial sensors to measure ground reaction forces and an athlete’s weight balance in skiing (Michahelles & Schiele, 2005), to produce detailed force vector analysis, effective inclination and ground reaction force power data in elite-level downhill skiing (Brodie et al., 2008), and develop a detailed biomechanical model and subsequently determine the start of run in, take off and landing points, flight angle, optimal flight technique, take off forces, and aerodynamic forces (drag and lift) associated with elite-level ski jumping (Ohgi et al., 2006, 2007; Seo et al., 2004a,b; Yamanobe & Watanabe, 1999). Although a valid technique in their own right, the customisation and use of inertial sensors in elite sporting contexts is still in the research and early adopter phase. Nonetheless, the application of signal processing on inertial sensor outputs combined with sport specific knowledge of key performance indicators has enormous potential in quantifying practically relevant information for coaches, athletes and competition judges involved in elite sport. At present elite-level half-pipe snowboarding seems well positioned to integrate technology and allow for some of the important technical aspects of the sport to be quantified. The aim of this area of monitoring however should not be to instrument everything on the body or equipment but rather understand what information is required and to use appropriate sensors to provide such information (Chi et al., 2005).
As previously established, half-pipe snowboarding is a sporting discipline long exuding an anarchistic and antiauthoritarian ideology with strong views on how performance should be valued and assessed. Successful integration of field-based monitoring afforded by micro technology must therefore be focussed upon relevant, practical information related strongly to training and competition performance.

1.7 Snowboarding-Specific Monitoring Technology

At the time of this study’s inception there were no available systems of automated objectivity tailored specifically for snowboarding. However a number of systems additional to the one customized by this study started to become available around 2007. As of 2010, there were a number of fast emerging technologies focused on providing objective data for snowboarding. Six are worthy of evaluation and are detailed in Table 1. Three of these systems Shadowbox™, Hangtimer™, and AIS/Catapult Innovations are wearable technologies using inertial sensors such as tri-axial accelerometers, rate gyroscopes, magnetometers and Global Positioning System (GPS) data as the primary technology whilst the other three, Video Analysis, EIM Solutions, Swatch/ST-Innovation are image based technologies not worn or attached to the athlete in any way. The two image-based systems developed by EIM-Solutions and Swatch/ST-Innovation, using manual post processing of Light-Emitting Diode (LED) photographic images (1000Hz) over a calibrated, software generated grid to generate objective jump height (JH) data achieved during snowboarding are currently at the forefront of integration into competition.

EIM Solutions and Swatch/ST-Innovation are the current objective data providers for the Ticket To Ride (TTR) World Snowboard Tour and O’Neill Evolution (Figure 6) snowboard events, respectively. The level of integration into elite competition is currently unmatched by the other systems shown in Table 1. These two image based systems possess the following advantages over others shown in Table 1: 1. They do not require the athlete to wear equipment. 2. They have extremely fast processing times, providing JH data approximately two seconds after an athlete finishes a run. 3. They are accurate and reliable (± 10.00 and ± 5.00cm for Swatch/ST-Innovation and EIM Solutions respectively) 4. They are extremely well integrated into elite competition. The disadvantages with these systems however include: 1. Long set up duration. 2. They require two people to run and maintain. 3. Jump height achieved during snowboarding aerial acrobatics is currently the only data provided. 3. They are not
commercially available removing the ability of coaches and athletes to use these systems in routine training environments.

Figure 6. The two image-based systems developed by EIM-Solutions and Swatch/ST-Innovation, using manual post processing of Light-Emitting Diode (LED) photographic images (1000Hz) over a calibrated, software generated grid to generate objective jump height (JH) data achieved during snowboarding are currently at the forefront of integration into competition. EIM Solutions and Swatch/ST-Innovation are the current objective data providers for the Ticket To Ride (TTR) World Snowboard Tour and O’Neill Evolution (Figure 6) snowboard events, respectively. These events are elite, influential and results achieved in these competitions arguably garner more respect from the snowboarding community than the FIS World Cup Tour and Olympic Games. This Image: Iouri "Ipod" Podladtchikov mid-spin on his way to taking out the 09/10 O’Neill Evolution Half-Pipe Competition, Davos Switzerland, 4th January 2010. Image © O’Neill.

The other three systems shown in Table 1 utilise various combinations of inertial sensors and signal processing to generate objective data specific to snowboarding. They are considered wearable technologies. Shadowbox™ utilise a filtered analysis of 100Hz tri-axial accelerometer, tri-axial rate gyroscope, tri-axial magnetometer and GPS data providing a three dimensional trajectory from which their objective information is derived. The AIS/Catapult Innovations system customized by this thesis has used various signal processing techniques with tri-axial accelerometer data to calculate air time (AT) and signal processing involving integration by summation of tri-axial rate gyroscope data to calculate degree of rotation (DR) and classify aerial acrobatics. The Hangtimer™ system utilises 100Hz tri-axial accelerometers and an unpublished signal processing technique to calculate information on AT only. All three wearable
The technologies shown in Table 1 have been integrated into competition but not at the same level or to the same extent as the image based systems from EIM Solutions and Swatch/ST-Innovation. Like these image based technologies, two of the wearable technologies (Shadowbox™ and Hangtimer™) do not provide transparent or published validity information and, considering the variety of sports they calculate data for, would be of concern to sports-scientists wishing to use them in a performance analysis context. The half-pipe snowboarding-specific AIS/Catapult Innovations system offers published validation information but it unavailable outside the Australian sports system.

A disadvantage of all wearable technology is the necessity for attachment to athletes or equipment, something not required by the image based systems. Many athletes would refuse to be instrumented in such a way for competition, especially in high risk sports such as snowboarding. The introduction of sophisticated packaging, allowing sensors to be packaged in a manner that is small and light enough to be embedded into competition bibs could solve this issue (Wordsworth, 2010). The advantages wearable technologies (apart from Hangtimer™) have over the image based systems is the range of data they can provide. The Shadowbox™ system is the most comprehensive, calculating data on AT, DR, JH, and spin rate (SR) whilst the AIS/Catapult Innovations system provides AT calculation and DR classification. Additionally, these wearable technologies are readily available for coaches and athletes to use in routine training, something currently impossible with the two image based systems. Until relatively recently, scientists, coaches, and athletes wishing to integrate some form of objectivity into half-pipe snowboarding training would be restricted to the use of video analysis. This thesis shows that advancements in technology can be successfully tailored for the sport of half-pipe snowboarding. The key considerations for systems providing objective, augmented feedback based on micro or other technologies for the sport of half-pipe snowboarding should however include: 1. The specificity and relevance of the information to the sport itself. 2. The ability to provide data without hindrance to an athlete’s performance. 3. The accuracy and reliability of the data provided. 4. The processing time required and 5. The accessibility of the method to the wider snowboarding community including coaches, athletes, judges and team support staff.
Table 1. Emerging technologies focused on providing sport specific objective data in elite snowboarding. Analysis by literature review / correspondence. Based on objective data for 1 athlete.

<table>
<thead>
<tr>
<th>System</th>
<th>Method</th>
<th>KPV</th>
<th>Error</th>
<th>Published</th>
<th>Process Time</th>
<th>Size (mm, g)</th>
<th>Labour</th>
<th>Integration</th>
<th>Availability</th>
<th>Cons</th>
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<tr>
<td>EIM Solutions</td>
<td>M1</td>
<td>JH</td>
<td>5.00cm</td>
<td>No</td>
<td>2.00s</td>
<td>NA</td>
<td>2</td>
<td>Yes I1</td>
<td>No</td>
<td>Unpublished</td>
</tr>
<tr>
<td>Swatch/ST Innovation</td>
<td>M2</td>
<td>JH</td>
<td>10.00cm</td>
<td>No</td>
<td>2.00s</td>
<td>NA</td>
<td>2</td>
<td>Yes I2</td>
<td>No</td>
<td>Unpublished</td>
</tr>
<tr>
<td>AIS/Catapult Innovations</td>
<td>M3</td>
<td>AT</td>
<td>0.03s</td>
<td>Yes</td>
<td>*150.00s</td>
<td>82x46x20</td>
<td>60.00</td>
<td>Yes I3</td>
<td>*Yes</td>
<td>Process Time</td>
</tr>
<tr>
<td>Shadowbox™</td>
<td>M4</td>
<td>DR</td>
<td>0.10s</td>
<td>No</td>
<td>NA</td>
<td>91x59x19</td>
<td>120.00</td>
<td>Yes I4</td>
<td>Yes</td>
<td>Unpublished</td>
</tr>
<tr>
<td>Hangtimer™</td>
<td>M5</td>
<td>AT</td>
<td>NA</td>
<td>No</td>
<td>5.00s</td>
<td>76x64x18</td>
<td>70.00</td>
<td>Yes I5</td>
<td>Yes</td>
<td>Unpublished</td>
</tr>
<tr>
<td>Video Analysis</td>
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<td>DR</td>
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<td>360.00s</td>
<td>NA</td>
<td>1</td>
<td>Yes I6</td>
<td>Yes</td>
<td>Process Time</td>
</tr>
</tbody>
</table>

SYSTEM, Company / Device name; METHODS, M1, M2, Manual post processing of Light-Emitting Diode (LED) photographic images captured at 1000Hz; M3, Signal processing (FFT and threshold based analysis) of tri-axial accelerometer data for air-time and signal processing (numerical integration of tri-axial rate gyroscope data) for trick classification [4]; M4, Filtered analysis of tri-axial accelerometer, tri-axial rate gyroscope and tri-axial magnetometer data outputs providing a 3D trajectory; M5, Unknown and unpublished signal processing of 100Hz tri-axial accelerometer data; M6, Manual post processing of 50Hz video footage with video analysis software using practice community definitions and rules; KPV, Key Performance Variable; AT, Air Time; DR, Degree of Rotation; SR, Spin Rate; JH, Jump Height; NA, information not available; ERROR, ± Absolute mean error; °, degrees; s, seconds; cm, centimetres; PROCESSING TIME, Time from the completion of a half-pipe run to viewing of objective information; *, Assessed downloading and calculating data from 3 hours of half-pipe snowboarding; SIZE / WEIGHT, Size and weight of system, size in length x breadth x depth (mm), weight in grams (g); LABOUR, How many people does it take to run / maintain system; INTEGRATION, Has the event been integrated into boardriding?; I1, Billabong Air & Style Snowboard Competition (TTR Event), Innsbruck Austria, 31/01/2009; I2, O'Neill Evolution Snowboard Tour, Davos Switzerland, 05/012008; I3, AIS Micro-Tech Pipe Challenge, Perisher Valley Australia, 30/07/2007; I4, AWSI Kite-Boarding Big Air Demo, Oregon USA, 17/09/2009; I5, Junior Snowboard Big Air Competition, Steamboat Springs USA, 2009; I6, Routine training for Australian national half-pipe snowboard team, Perisher Valley Australia, 30/07/2007; AVAILABILITY, Commercial, Available through commercial means; Contracted, Only available as a contracted service by the provider; *, Commercially available however half-pipe specific software still a prototype system. CONS, Major disadvantages associated with each system of automated objectivity.
1.8 The Integration Of Automated Objectivity

Computer scientists claim that the instrumentation of athletes and the provision of augmented and objective feedback are nothing more than pervasive computing (Baca, 2006). In an engineering, sport science, and performance context however, this instrumentation is far more than that (Fuss, 2008; Sands, 2008). In many sports, objective information tailored for a specific discipline is unavailable due to lack of suitable instrumentation, which often enters the sports scene only very slowly. The rationale for this is that instrumentation embedded into equipment is often constrained by rules, laws and regulations surrounding existing competitions, and instrumentation worn by athletes is often impeded by the size and mass of specific sensors which require power supplies, transmitters, receivers, storage devices, and the necessity to be attached to the athlete’s body (James, 2006; Knoll, 2006; Sands, 2008). These issues thereby stifle the integration of innovative concepts with the potential to enhance both performance assessment and spectator immersion in many sporting disciplines (Fuss, 2008). Sports federations and controlling bodies routinely need to be convinced that in many cases, the provision of tailored information by using technology and instrumentation is only possible by relaxing specific regulations and by collaboratively elucidating solutions acceptable to both the implementers (sport scientists, developers, engineers) and those affected (sporting communities). The federations and controlling bodies should have no reason to object if instrumented equipment displays the same size, mass, position of the centre of mass, moment of inertia, and vibration characteristics as the uninstrumented one and that an instrumented athlete still retains unrestricted performance capabilities (Chi et al., 2005; Fuss, 2008, Knoll et al., 2006).

It is largely unknown if competitive half-pipe snowboarding can indefinitely maintain a purely subjective style of performance assessment in an era when there are calls for more objectivity in judging Olympic sports. Recent opinion has identified the need for a system of judging to be introduced that is based upon more accurate, reliable and stringent measures, with the caveat that it must do so without stifling athletic freedom of expression. In addition to these external influences, internal forces also need to be considered. Miah (1998) evokes sport’s overall self-annihilating teleology; that increased numbers of athletes ultimately achieve ‘optimal performance’, thereby outgrowing the structure of the game or competition. Sports are then often forced to adopt altered performance assessment methods, equipment changes, or altered game rulings to again separate similarly capable athletes. It is quite possible that elite half-
pipe snowboarding is not immune to this teleology. The most likely scenario would be a large number of athletes complete the most difficult aerial acrobatics with the same air times and execution levels in competition, thereby impinging on the capacity of current subjective judging criteria to reliably assess performance. Recent technological advancements may however provide the sport with an ability to remove controversial results or at least provide judges an additional tool to utilise in routine competition environments and during dispute situations. Nevertheless the major concern of many sporting communities is that improvements in sport science and technology possess a latent ability to remove the stylistic components from a sporting discipline and thereby reducing the magic of a performance to a series of mathematical equations (Brodie, 2008; Miah, 2000; Miah, 2002; Morgan, 1994; Tenner, 1996). Although this is a concern in a competition judging context, the potential for coaches and athletes to utilise technologically based augmented feedback in routine training environments should be less complex. Accurate and reliable feedback is a key contributing factor to improving athletic performance and provides a basis for developing and implementing individual athlete strategy, dependable assessment of performance progression, and team selection criteria. It should therefore be seriously considered in the normal practice scheme for elite athletes, regardless of discipline (Liebermann et al., 2002).

Perhaps the most significant aspect of change in sport is that any such action can dictate the future of a sport in a way that makes reversing such changes very difficult (Miah, 1998, 2000). Technology often has additional and unintended consequences and possesses the capacity to effect change beyond its original purpose (Tenner, 1996; Miah, 1998). Hence, athletes, coaches, competition judges and the sports governing bodies are often reluctant to adopt new equipment and performance assessment technologies (Chi et al., 2005). In many cases, the rules associated with particular sports must be changed themselves in order to accommodate new technology and innovative concepts. Furthermore, athletes, coaches, and competition judges often need to be convinced that their cooperativeness is essential for increasing mainstream interest and performance assessment accountability in their particular sporting discipline. This issue is compounded by further complexities in half-pipe snowboarding, a sport with an underlying anarchistic and anti-authoritarian ideology, a habitual focus on athletic individuality and freedom of expression, and a community with strong views on how performance should be valued and assessed. As such, the integration of technology (whether focussed on performance assessment in training or competition) into half-pipe
snowboarding will no doubt provide sport scientists (as implementers) and the practice community (those affected) with challenges. As argued by Miah (2005), changes, technological or otherwise, should be preceded with substantial discussion about what future is sought for a specific sport and thus, where limits might be drawn on the changes. Regardless, defining who should determine the nature of a sport ought not to be a difficult issue. It seems imperative that implementers consider and respect the personal issues of those affected and ensure practicing communities (such as those shown in Figure 6) are allowed to articulate their interests in forums that convey influence (Morgan, 1994). Furthermore, practice communities should be provided an element of control over the integration of any innovative concepts into their sport (Fuss, 2008, Miah, 1998; Miah, 2005a; Morgan, 1994).

1.9 Snowboard Performance Assessment Innovation

Comprehensive monitoring of athletes is necessary in order to allow coaches and competition judges to make informed decisions regarding longitudinal training progressions and acute performance levels respectively (Smith, 2003). Although undertaken with consideration of the sport’s traditional philosophies this thesis is focused on objective methods to improve athletic performance and judging reliability. The body of work therefore examines the use of technology to introduce relevant, objective information into half-pipe snowboarding through a multitude of projects. The purpose of this thesis was ultimately to: 1. Establish the existence of and quantify the relationship between relevant, objective key performance indicators (KPI’s) and subjectively judged scores in elite half-pipe snowboarding competition. 2. Customise, trial and validate wearable technology to automatically quantify objective information on these key performance indicators. 3. Integrate this automated performance assessment concept into elite half-pipe snowboarding competition. 4. Assess the community perception and potential sociological impact of this and future integration.

From a sport science perspective, those at the elite level of snowboarding can no longer detach themselves from the connotations and underlying motives associated with the term athlete, whether the expression fits the practice community’s underlying cultural ideology or not. This thesis introduces a performance assessment concept that although derived from principles and practices routinely used in more traditional sporting disciplines, has been tailored specifically for elite snowboarding.
1.10 References


98. Sanders, R., and Burnett, A. (2004). Technique and timing in women's and men's reverse one and one half somersault with two and one half twists (5335D) and men's reverse one and one half somersault with three and one half twists (5337D) 3 m springboard dives. Sports Biomechanics, 3, 29-41.


2 METHODS / EXPERIMENTAL

2.1 Key Performance Indicators

This thesis is focused on success in elite half-pipe snowboarding competition and examines the use of technology to introduce objective information into a sport that currently relies on purely subjective performance assessment. The introduction of sport specific objective information as a form of augmented feedback is now a fundamental aspect of athletic training regimens and is a pursuit that is routinely utilised within sport science fields in an attempt to enhance athletic performance. This study is concerned not only with enhancing athletic performance but also with enhancing the reliability of training and competition performance assessment. Augmented feedback of an objective nature however must be specific to the sport in order to have any beneficial effect on performance. This study therefore establishes the objective key performance indicators (KPI’s) that are specific to the sport of half-pipe snowboarding based on their relationship to subjectively judged scores in competition. As these objective performance indicators are novel and unpublished within the scientific literature, we have established definitions for air-time, degree of rotation and their associated variations to allow for repeatable and reliable measurement during future research.

2.1.1 Definitions

Air-time begins the first moment there is no longer contact between the snowboard and the snow (Figure 7) and ends the moment any part of the snowboard comes in contact with the snow following an attempted aerial acrobatic manoeuvre. There are additional variations in aerial acrobatic air-time that have practical relevance to half-pipe snowboarding performance and will allow enhanced training and competition performance assessment. These variations also require definition to allow reliable, repeatable analysis and are therefore provided below.

*Air-time (AT)* is measured in seconds and reflects the amount of time the athlete spends in the air during a half-pipe snowboarding aerial acrobatic manoeuvre, beginning the first moment there is no longer contact between the snowboard and the snow and ending the moment any part of the snowboard comes in contact with the snow following an attempted aerial acrobatic manoeuvre.
Total air-time (TAT) is measured in seconds and calculated by adding together all recorded air-times (typically 6 - 8) during a half-pipe snowboard run.

Average air-time (AAT) is also measured in seconds and is calculated by dividing total air-time by number of by the total number of aerial acrobatic manoeuvres completed throughout the duration of a half-pipe snowboarding run.

Highest individual air-time (HIAT) is measured in seconds and is the individual aerial acrobatic manoeuvre performed throughout a half-pipe snowboard run that achieves the largest air-time.

**Figure 7.** Air time begins the moment there is no longer contact between the snowboard and snow (as shown in this image) during all half-pipe snowboard aerial acrobatic manoeuvres. Professional snowboarder competing at the Burton Open Australian Half-Pipe Championships. Perisher Valley, Australia 2008. Image: Heidi Barbay.

Rotation terminology used by half-pipe snowboarding practice communities is not based upon assessment of exact degree of rotation achieved. It is based upon a sport specific approximation quantised to 180° multiples (i.e. 180°, 360°, 540°, 720°, 900°, 1080°, and 1260° rotations). The take-off (Figure 8) and more specifically the landing angles (similar but opposite to the take-off angle) associated with half-pipe snowboarding aerial acrobatics generate a situation where exact degree of rotation achieved will always be less than the terminology used to describe it. Theoretically, the degree of rotation achieved during rotations performed predominantly around a single
axis is at least, $90^\circ$ less than the rotation the athlete is credited with based on conventional terminology.

**Figure 8.** The take-off (shown here) and landing angles (similar but opposite to the take-off angle) associated with half-pipe snowboarding aerial acrobatics generate a situation where exact degree of rotation achieved will always be less (approximately $90^\circ$) than the terminology used to describe it. Professional snowboarder competing at the Burton Open Australian Half-Pipe Championships. Perisher Valley, Australia 2008. Image: Heidi Barbay.

Rotational terminology can be based upon the following rules; an athlete will land aerial acrobatics travelling in the same direction they were initiated with in $180^\circ$ (straight air), $540^\circ$, $900^\circ$ and $1260^\circ$ rotations. In contrast an athlete will land travelling in the opposite direction of the initiation during $360^\circ$, $720^\circ$ and $1080^\circ$ rotations. These rules apply only in half-pipe and quarter-pipe snowboarding (resultant of the take-off and landing occurring on the same lip). Although snowboarders can ride forwards or backwards, these rules apply regardless of the direction of travel when aerals are initiated. As with air-time, it is believed the key performance indicator of degree of rotation should be defined in order for sport scientists to accurately and reliably calculate degree of rotation. Degree of rotation calculation begins the first moment there is no longer contact between the snowboard and the snow and ends the moment any part of the snowboard comes in contact with the snow following an attempted aerial acrobatic manoeuvre. There are subcomponents of aerial acrobatic degree of rotation that have practical relevance to half-pipe snowboarding performance and will allow enhanced
training and judging protocols. As is the case with air time these variations require definition to allow reliable, repeatable analysis and are provided below.

**Degree of rotation (DR)** is measured in degrees and reflects the amount of rotations (calculated using the rules associated with the sport specific approximations) an athlete completes during individual aerial acrobatic manoeuvres performed during a half-pipe snowboarding routine. Note: aerial acrobatic manoeuvres that contain no sport specific rotational component (‘straight airs’) still generate a degree of rotation value of 180° and should also be deemed a 180° rotation when using video based analysis. This is because the athlete takes off and lands on the same half-pipe lip and therefore turns the snowboard through approximately 180°. The first aerial acrobatic manoeuvre with a sport specific rotational component however is a 360° rotation. Note: Aerial acrobatics performed in the opposite direction to normal downward travel (i.e. back toward the beginning or top of the half-pipe course instead of the bottom) described by the snowboarding community as ‘alley-oop’ manoeuvres were given an extra 180° of quantised degree of rotation to account for the added difficulty in completing the trick and to comply with ‘practice community’ terminology. For example, an athlete completing a normal straight air (taking off and landing facing the same direction) generate 180° of rotation whereas an athlete completing an alley-oop manoeuvre where they take off and land facing the same direction generate 360° of rotation in this study.

**Total degree of rotation (TDR)** is measured in degrees and calculated by adding together all recorded rotations associated with each aerial acrobatic manoeuvre performed (typically 6 - 8) during a half-pipe snowboard run.

**Average degree of rotation (ADR)** is also measured in degrees and is calculated by dividing total degree of rotation by the total number of aerial acrobatic manoeuvres completed throughout the duration of a half-pipe snowboarding run.

**Highest individual degree of rotation (HIDR)** is measured in degrees and is the individual aerial acrobatic manoeuvre performed throughout a half-pipe snowboard run that achieves the largest degree of rotation.

**Highest cumulative degree of rotation (HCDR)** is measured in degrees and is calculated by adding together the total degree of rotation associated with the largest consecutive
series of rotational aerial acrobatic manoeuvres. For example this parameter is associated with the total degree of rotation associated with aerial acrobatic manoeuvres that contain a rotational component that are performed ‘back to back’ or in a consecutive ‘group’. Athletes can perform a string or cluster of consecutive aerial acrobatic manoeuvres that all possess a rotational component during a half-pipe snowboard run. Strings of consecutive rotational manoeuvres can however be interspaced with what is termed a straight air or a number of straight airs (aerial acrobatic manoeuvres that contain no rotational component) generating a half-pipe snowboard run containing a number of different clusters of ‘back to back’ rotational acrobatic manoeuvres. There is a snowboard community perception that athletes who string together a consecutive series of aerial acrobatics with a high rotational component score highly in competition as sequences of consecutive rotational acrobatics increase the difficulty and risk associated with the routine. The Highest Cumulative Degree of Rotation is focussed on the series of consecutively performed rotational manoeuvres that obtains the highest total degree of rotation throughout a half-pipe snowboard run. This is different to total degree of rotation which simply adds together the degree of rotation associated with all acrobatic manoeuvres that have a rotational component performed within a completed half-pipe snowboard run, regardless of whether or not those rotational manoeuvres were performed consecutively or ‘back to back’.

2.1.2 Equipment And Data Collection

Athletic performance assessment is now routinely transferred out of the laboratory and into the field (Lyons, 2005) but until now, there has been no available scientific data associated with the relationships between objective performance indicators and subjectively judged competition scores for elite half-pipe snowboarding. Although there is community perception that air-time (AT) and degree of rotation (DR) play a major role in half-pipe competition success, the combinations of these variables, the amount of shared variance they explain in competition scores and the exact magnitudes of differences in AT and DR between athletes who succeed in competition and those that do not however, can only ever be determined objectively. Laboratory based objective performance assessment of half-pipe snowboarding (and snowboarding in general) is currently impossible. Video analysis is used in snowboarding as a form of performance analysis yet it is primarily focused on subjective enhancement of style and trick execution. Video based analysis can however also be used to objectively assess performance variables specific to the sport in the field. Through the use of video based
analysis this thesis defines objective key performance indicators (KPI’s) specific to half-pipe snowboarding, establishes their relationship to subjectively judged scores, provides evidence of a longitudinal trend of continually increasing performance levels at the elite level, defines the smallest worthwhile change (SMC) required for elite level competition performance enhancement, and compiles performance information associated with the highest level half-pipe snowboard competitions. In doing so this thesis provides evidence that an in-field derived video based analysis can be used to reliably quantify relevant and practical objective information pertaining to the sport of half-pipe snowboarding and that this information can be used to enhance performance assessment in training and competition.

In order to quantify objective information on half-pipe specific key performance indicators for the competitions analysed during this study (Burton Open Australian Half-Pipe Championships, Fédération Internationale de Ski (FIS) World Cup (WC) Half-Pipe Snowboarding Competitions, AIS Micro-Tech Pipe Challenge, and the 2006 Winter Olympic Games Half-Pipe Snowboarding Competition), panning video footage of each half-pipe run was collected using a 3CCD 50 Hz digital video camera (Sony, TRV950E, Tokyo Japan, www.sony.com) from the bottom and centre of the half-pipe (Figure 9). Video footage captured during these competitions was uploaded and digitized by video analysis software (Dartfish, Connect 5.5, Fribourg Switzerland, www.dartfish.com). Data was processed retrospectively for all competitions. Air time was analysed using a digital stopwatch associated with the video analysis software (resolution = 0.02s) and degree of rotation data was determined using ‘practice community’ rules for aerial acrobatic manoeuvre classification (as previously described in section 3.1). Only competition runs deemed (by the primary author) to be ‘cleanly completed’ were assessed by this study. Any run deemed to have suffered from falls, stops, major places of hands onto snow following aerial acrobatic landings and associated losses of momentum were removed from the analysis. Not all athletes were able to perform more than one completely clean competition run. Experimental procedures associated with these half-pipe snowboarding competition studies were approved by the Ethics Committee of the Australian Institute of Sport on 18th August 2005 (ref: 20050808) and in accordance with Griffith University requirements, cleared under special review in January 2008 (ref: PES/01/08/HREC).
Figure 9. During all competitions analysed during this study panning video footage of each half-pipe run was collected using a 3CCD 50 Hz digital video camera (TRV950E, Sony, Tokyo Japan, www.sony.com) from the bottom and centre of the half-pipe. Photographers, videographers and primary author capture the action during the Burton Open Half-Pipe Championships. Perisher Valley, Australia 2007. Image: Heidi Barbay.

An intra-researcher reliability score was calculated for the video-based method associated with air time calculation. The primary author undertook a test-retest analysis by calculating the air times associated with 100 aerial acrobatic manoeuvres twice (each analysis was conducted one week apart). Test-retest measurements associated with air time showed an almost perfect correlation ($r = 0.99 \pm 0.00$, $p = <0.001$, $r^2 = 0.99$, $SEE = 0.01$, $n = 100$, $PE = 0.99AT – 0.003$). We additionally adopted a Typical Error of Measurement (TE) approach (Hopkins, 2004) to calculate the absolute error within this air time measurement method and also the error associated with air times routinely generated during elite half-pipe snowboarding. Performance changes must be larger than the TE for a specific KPI to be deemed clinically relevant. TE was calculated as follows; $(TE = SD \text{ Difference Scores} / \sqrt{2})$. The TE associated with this particular video based air-time calculation method conducted by the primary author = 0.01s.

An intra-researcher reliability score was calculated for the video-based method associated with degree of rotation calculation. The primary author undertook a test-retest analysis by calculating the air times associated with 100 aerial acrobatic manoeuvres twice (each analysis was conducted one week apart). Test-retest measurements associated with air time showed a perfect correlation ($r = 1.00 \pm 0.00$, $p$
= <0.001, \( r^2 = 1.00, SEE = 0.00, n = 100, PE = 1.00DR - 0.00 \)). There were zero occasions where the primary author incorrectly identified an aerial acrobatic manoeuvre. As no aerial acrobatic manoeuvres were classified differently during the test-retest analysis, the TE associated with this particular video based degree of rotation calculation method conducted by the primary author = 0.00°.

2.1.3 Statistical Analysis

This study allowed the correlation of individual objective key performance indicators including TAT, AAT, HIAT, TDR, ADR, HIDR, HCDR to a criterion reference (subjectively judged competition scores) during the Burton Open Australian Half-Pipe Championships over three years (Table 5), three consecutive FIS WC Half-Pipe Snowboarding Competitions in 2006 (Table 8), and the AIS Micro-Tech Pipe Challenge in 2007 (Table 12). The individual KPI's that showed the strongest correlations to subjectively judged scores were then combined in multiple linear regression (enter method) to determine the amount of shared variance they explain in competition scores during these elite-level half-pipe snowboard events (Table 6, Table 9, Table 13 respectively). All correlations are presented as correlation co-efficient \( (r) \pm 95\% \) confidence limits \( (95\% CL) \), p value \( (p) \), coefficient of determination \( (r^2) \), standard error of the estimate \( (SEE) \), sample size \( (n) \) and the predicted score regression equation \( (PS) \).

We additionally adopted the approach of magnitude-based inferences (Batterham and Hopkins, 2006) to analyse differences in KPI performance between groups (athletes achieving top three podium finishes and those achieving results outside the top three in the Burton Open Australian Half-Pipe Championships and the AIS Micro-Tech Pipe Challenge and between the Finalists and Qualifiers during the FIS WC half-Pipe Snowboard Competitions). Means associated with ‘top three’ (T3) finishes were obtained using data only from the three competition runs associated with the top three final rankings whilst means associated with ‘outside top three’ (OT3) finishes were obtained using data from the rest of the competition field. Means associated with Finalists were obtained using data only from the competition runs associated with the top twelve final rankings (Finalists) whilst means associated with those athletes ranking outside the finals round (Qualifiers) were obtained using data from the rest of the competition field (i.e. those athletes that did not make the finals round). The effect size statistic was generated for absolute differences in each variable to assess magnitude of difference between the means of KPI performance by the top three final rankings (T3)
and those final rankings outside top three (OT3) finish places in the Burton Open Australian Half-Pipe Championships and the AIS Micro-Tech Pipe Challenge (Table 7 and Table 14 respectively) and between Finalists and Qualifiers in the FIS WC half-Pipe Snowboard Competitions (Table 10), allowing relative importance of variables to be assessed in terms of their value in contributing to successful competition outcome. Effect sizes were established as follows (ES = (difference in mean / pooled SD). The criteria for interpreting effect size were: <0.2, trivial; 0.2-0.6, small; 0.6-1.2, moderate; 1.2-2.0, large; and > 2.0, very large (Batterham and Hopkins, 2006). Additionally, statistical significance associated with the differences between the mean data of athletes achieving top three finishes (T3) and those achieving results outside the top three (OT3) and between Finalists and Qualifiers were calculated with an Independent t-test analysis.

The reliability and usefulness of KPI analyses is a critical issue. There are two key criteria in establishing the usefulness of a test: the TEM (the noise or error in the test) and the smallest worthwhile change in performance terms. The smallest worthwhile change for elite athletes is approximately half the coefficient of variation (CV %) in KPI performances from competition to competition or more simply, calculated as 0.2 x the between-subject standard deviation of that event or test, based on the concepts of Cohen’s Effect Size (Hopkins, 2004; Pyne, 2003). As two of the FIS World Cup Half-Pipe Snowboarding Competitions (Leysin Switzerland) were conducted on the same half-pipe course, on consecutive days, and for the most part contained the same athlete sample, we additionally adopted the approach of ‘smallest worthwhile change’ to analyse the changes in KPI performance required for athletes to improve their performance from competition to competition (Table 11). Statistical significance associated with the mean data of athlete’s KPI performances (finalists, n = 12 male and n = 6 female performances) between each competition were calculated with a One Way ANOVA. All group mean data are presented as mean ± SD and all mean differences are presented as mean ± 95% confidence limits.

The Burton Open Australian Half-Pipe Championships were assessed over a three year period and as such, the longitudinal changes in half-pipe snowboard specific KPI performance could additionally be addressed (Figure 17). Statistical significance associated with the mean data of athlete’s KPI performances (finalists, n = 12 male and n = 6 female performances) between each year of the competition were calculated with a One Way ANOVA. All group mean data are presented as mean ± SD and all mean
differences are presented as mean ± 95% confidence limits.

As data collection during the 2006 Winter Olympic Games Half-Pipe Snowboarding Competition involved a limited sample of the competition performances (collecting data on the finals round only) this study was used to describe the current level of performance (as of 2006) in elite half-pipe snowboarding competition. Data is presented as mean ± SD of Finalist KPI performances for both men and women’s competitions (Table 15).

All correlations ($r$), goodness of fit statistics ($r^2$), standard error of the estimates (SEE), p-values ($p$), prediction equations (PE), Independent t-test and ANOVA’s were calculated using SPSS 13.0 for Windows (Graduate Student Version, SPSS Inc, Chicago Illinois USA, www.spss.com). All confidence limits (CL) were performed using Excel spreadsheets (Hopkins, 2004). All confidence limits were set at 95% and statistical significance was set at $p < 0.05$. All graphs were generated using GraphPad Prism 4.01 (GraphPad Software Inc, La Jolla, CA, USA, www.graphpad.com).

### 2.1.4 Burton Open Australian Half-Pipe Championships

This study was an objective analysis of half-pipe snowboarding performance at the Burton Open Australian Half-Pipe Championships over three years (2006, 2007, and 2008). The performances associated with a total of 115 men’s finals half-pipe snowboarding competition runs (2006, n = 28; 2007, n = 57; 2008, n = 30) and a total of 54 women’s finals half-pipe snowboarding competition runs (2006 n = 14; 2007, n = 28; 2008, n = 12) were assessed throughout this study. Data collection was performed during the southern hemisphere winter season at Perisher Blue Ski Resort (altitude 1720 m) on the resort’s custom snowboard half-pipe (Length = 80.00m, Width = 18.0m, Height = 5.00m, Inclination = 15°). Data collection associated with the annual Burton Open Australian Half-Pipe Championships occurred on 28th August 2006, 9th September 2007, and 4th September 2008. Environmental and snow temperatures for the events in 2006, 2007, and 2008 were 7°C and -0.5°C, 9°C and -0.6°C, 5°C and -1.0°C respectively.

Judging during the Burton Australian Open Half-Pipe Championships was conducted in the same manner as all elite half-pipe snowboarding competitions, with a team of professional judges using the subjective measure Overall Impression (OI) to generate performance scores and overall final rankings. In 2006, 2007 and 2008, there were 3, 5,
and 5 judges respectively. In 2006, 2007, and 2008, each judge scored competition performances out of a maximum of 10, 20, and 20 points respectively, generating a final competition score with a combined maximum score of 30, 100 and 100 points respectively. In all three competitions, athletes were provided the opportunity to complete three runs. The run associated with the highest score for each athlete was used to determine final competition rankings.

2.1.5 Fédération Internationale de Ski (FIS) World Cup Competitions

This study was an objective analysis of half-pipe snowboarding performance during three consecutive Fédération Internationale de Ski (FIS) World Cup competitions (Kreischberg Austria, K1, 09/01/2006; Leysin Switzerland, L1, 18/01/2006; Leysin Switzerland, L2, 19/01/2006. The performances associated with a total of 100 cleanly completed men’s half-pipe snowboarding competition runs (K1, n = 46; L1, n = 29; L2, n = 25) and a total of 50 cleanly completed women’s half-pipe snowboarding competition runs (K1, n = 24; L1, n = 13; L2, n = 13) were assessed during this study. We analysed only the highest scoring run from each athlete. Consequently each athlete’s performance contributes only once to the analysis associated with each competition. Data collection was performed during the northern hemisphere winter season in 2006 at Kreischberg Austria on 9th January (K1), Leysin Switzerland on 18th January (L1) and again at Leysin Switzerland on 19th January (L2). Data collection was performed on each resort’s custom snowboard half-pipe (Kreischberg Austria, Length = 120.00m, Width = 18.5m, Height = 5.40m, Inclination = 17°; Leysin Switzerland, Length = 150.00m, Width = 18.00m, Height = 5.50m, Inclination = 18°).

Judging during all FIS World Cup competitions are conducted by a team of professional snowboard judges using the subjective measure Overall Impression (OI) to generate performance scores and overall final rankings. During each competition associated with this study, there were 5 judges with 1 additional Head Judge. The Head Judge’s role is to oversee and maintain the reliability of the judging process. The Head Judge does not contribute an individual score to any performance). Each judge scored competition performances out of a maximum of 10. All judges’ scores (except for the Head Judge’s score) are then combined for each run generating a total score with a maximum value of 50 points. Competitions were conducted using two heats where athletes in each heat are provided the opportunity to complete two runs. The run associated with the highest judged score for each athlete was used to determine competition rankings. The best 6
and the best 3 performing athletes (men’s and women’s competitions respectively) from each heat move into the finals round. These athletes (Finalists) are again provided the opportunity to complete two runs with the highest judged score for each athlete used to determine competition final rankings.

2.1.6 Australian Institute of Sport (AIS) Micro-Tech Pipe Challenge

This study was an objective analysis of half-pipe snowboarding performance at the AIS Micro-Tech Pipe challenge (2007). Ten elite-level male Australian half-pipe snowboarders were recruited and ultimately volunteered to participate in this study. The performances associated with a total of 18 half-pipe snowboarding competition runs were assessed during this study. Data collection was performed during the southern hemisphere winter season of 2007 on Monday 30th July at Perisher Blue Ski Resort (altitude 1720 m) on the resort’s custom snowboard half-pipe (Length = 80.00m, Width = 18.0m, Height = 5.00m, Inclination = 15°). Environmental and snow temperatures for this event was 7°C and 0.4°C respectively.

Subjective judging during the AIS Micro-Tech Pipe challenge was conducted in the similar manner as all elite half-pipe snowboarding competitions, using the subjective measure Overall Impression (OI) to generate performance scores and overall final rankings. The AIS Micro-Tech Pipe Challenge however only used one professional judge to generate scores as opposed to a team of professional judges. Athletes were awarded an overall impression score out of 10 for each competition routine by this judge. Athletes were provided the opportunity to complete three runs. The run associated with the highest score for each athlete was used to determine final competition rankings.

2.1.7 2006 Winter Olympic Games

This study was an objective analysis of half-pipe snowboarding performance at the Winter Olympic Games (2006). The performances associated with a total of 11 cleanly completed men’s half-pipe snowboarding competition runs and a total of 10 cleanly completed women’s half-pipe snowboarding competition runs were assessed during this project. This project only assessed half-pipe snowboarding performances in the finals rounds for both men and women and additionally only the highest scoring run from each athlete. Consequently each athlete’s competition performance contributes only once to the analysis associated with each competition. Data collection for the men’s
and women’s events was performed during the northern hemisphere winter season in 2006 at Bardonecchia Italy on 12th February and 13th February respectively. Data collection was performed the resort’s custom snowboard half-pipe (Length = 145.00m, Width = 18.0m, Height = 5.70m, Inclination = 16°). Environmental and snow temperatures for the men’s and women’s events were 3°C and -12°C, and 3°C and -8°C respectively.

Judging during the 2006 Winter Olympic Games half-pipe snowboarding competition was conducted by a team of professional snowboard judges using the subjective measure Overall Impression (OI) to generate performance scores and overall final rankings. During each event, there were 5 judges with 1 additional Head Judge. The Head Judge’s role is to oversee and maintain the reliability of the judging process. The Head Judge does not contribute an individual score to any performance). Each of the five judges scored competition performances out of a maximum of 10. All judge’s scores (except for the Head Judge’s score) are then combined for each run generating a total score with a maximum value of 50 points. Competitions were conducted using a qualification and a finals round. In the qualification round, athletes were provided the opportunity to complete two runs. The run associated with the highest judged score for each athlete was used to determine competition rankings. The best 12 performing athletes in both the men’s and women’s qualifications rounds move into the finals. These athletes (Finalists) are again provided the opportunity to complete two runs with the highest judged score for each athlete used to determine competition final rankings.

2.2 Sports Technology

Accurate and reliable feedback is a key contributing factor to improving athletic performance. Quantifying sport specific key performance indicators most highly correlated with success in snowboard competition provides an innovative solution for developing and implementing individual athlete strategy, dependable assessment of performance progression, and team selection criteria. This type of objective feedback however must be provided in a timely manner to be considered a key contributing factor in improving athletic performance and additionally improving athletic performance assessment (Kirby, 2009; Fuss, 2008). The video analysis method used in this study to quantify objective information on half-pipe snowboarding performance is unfortunately labour intensive and associated with a large time delay in information feedback. Advancements in microelectronics and other technologies however mean it is now
possible to build instrumentation small and unobtrusive enough for a number of field-based applications including snowboarding performance assessment (James et al., 2004; Fuss, 2008). The objective data generated by wearable and other technologies must however possess high validity and reliability and must allow unhindered performance to be useful in elite sporting contexts (Knoll et al., 2006). The capacity of inertial sensors to accurately measure human motion thousands of times per second in multiple axes and at multiple points on the body is now well established and on-board data storage negates the need for equipment tethering (James, 2006). This study therefore customised wearable sensor technology to develop an automated performance feedback system suitable for calculation of air time and degree of rotation in routine training and competition environments. The customization process consisted of three parts. 1. Collection of both video data (criterion reference) and inertial sensor data (practical method) from elite-level performance during half-pipe snowboarding training and competition runs. 2. Development of mathematical signal processing techniques to automatically quantify objective information on half-pipe snowboard specific key performance indicators (air time and degree of rotation). 3. Validation of those signal processing techniques against the video based criterion reference.

2.2.1 Equipment

Implementation of previously developed inertial sensors were used throughout data collection process. Inertial sensors (Figure 10) were comprised of one tri-axial accelerometer (Kionix, KXM52-1050, 100Hz, ± 6g), three rate gyroscopes (Analogue Devices, ADXRS300, 100Hz, ± 1200 deg s⁻¹, 20.94 rad s⁻¹) aligned orthogonally to measure rotation in three directions, ARM based micro processor (Atmel, AT91 SAM7X256), 256MB of trans flash memory, and a 600mAh Lithium Ion rechargeable battery housed within an impact resistant injection moulded plastic case (Mackintosh, et al., 2008). The quantification of air-time associated with aerial acrobatic manoeuvres performed during half-pipe snowboarding only requires signal processing of tri-axial accelerometer data. The quantification of degree of rotation and the associated classification of aerial acrobatics into sport specific rotational groups requires signal processing of a combination of tri-axial rate accelerometer and tri-axial rate gyroscope data. The movement patterns associated with half-pipe snowboarding are biomechanically complex however the rotations in longitudinal axes and the movement directions in the orthogonal axes could describe the movement. The quantification of air time and degree of rotation was focussed on signal processing of the patterns
generated by inertial sensor data with gross reference to these sensor axes. Raw tri-axial accelerometer and tri-axial rate gyroscope data was stored on board the sensor unit for the duration of all data collection periods and was sampled post collection by a computer software suite (developed in house by Colin Mackintosh of the Applied Sensors Unit at the Australian Institute of Sport (Mackintosh et al., 2008).

Figure 10. Previously developed inertial sensor unit which contains one tri-axial accelerometer (Kionix, KXM52-1050, 100Hz, ± 6g), three rate gyroscopes (Analogue Devices, ADXRS300, 100Hz, ± 1200 deg s-1, 20.94 rad s-1) aligned orthogonally to measure rotation in three directions, an ARM based micro processor (Atmel, AT91 SAM7X256), 256MB of trans flash memory, and a 600mAhr Lithium Ion rechargeable battery housed within an impact resistant injection moulded plastic case (Mackintosh et al., 2008).

2.2.2 Experimental Procedure

Tri-accelerometer components underwent two-point static calibration in three orthogonal axes (up/down, forward/back and left/right) prior to each data collection session aligning each axes of sensitivity with and against the direction of gravity. Tri-axial rate gyroscope components underwent a two-point calibration integrating angular velocity over time throughout 0 and 90 degrees in three orthogonal axes (yaw, pitch, roll) prior to each data collection session (Green & Krakauer, 2003). There was only
small short term drift associated with the gyroscope calibration method and the validation studies conducted in this thesis show that it is verified. Panning video footage of each half-pipe run was collected using a 3CCD 50 Hz digital video camera (Sony, TRV950E, Tokyo Japan, www.sony.com) from the bottom and centre of the half-pipe and included every aerial acrobatic manoeuvre attempted (Figure 9). Video footage captured during these competitions was uploaded, digitized, and analysed by video analysis software (Dartfish, Connect 5.5, Fribourg Switzerland, www.dartfish.com). Tri-axial accelerometer data, tri-axial rate gyroscope data and video footage was synchronised via mechanical artefact before and after each run. Analysis of inertial sensor data and the subsequent development of signal processing techniques for automatic quantification of air time in Method 1 and Method 2 were carried out with the custom software (Figure 11) developed in house (Mackintosh et al., 2008) and using a combination of the raw numerical data generated by this custom software and Matlab 10.0 (The MathWorks, Natick, MA, USA, www.mathworks.com) respectively. Analysis and development of signal processing techniques for the classification of aerial acrobatics into sport-specific rotational groups (degree of rotation) were carried out with custom software and numerical integration of raw data.

Figure 11. Computer software suite developed in house (Mackintosh et al., 2008) providing the capacity to simultaneously view and analyse video footage (left) and inertial sensor data (right) synchronized by mechanical artefact. The raw, unfiltered tri-axial accelerometer data obtained during a half-pipe snowboard run produces a distinct and repeatable pattern, displaying elevated accelerations throughout the take off and landings. The quantification of air time associated with each aerial manoeuvre using accelerometer data is possible as a result of this pattern.
The use of 50Hz video footage as a criterion reference for air time quantification is a user friendly method in the harsh environmental conditions such as those encountered during data collection for snowboarding. The tri-axial accelerometer data however is sampled at 100Hz and as such it was necessary to assess whether or not the 50Hz video footage possessed sufficient resolution to be used as a criterion reference for an automated system sampling at a higher rate. As such high speed video footage (200Hz) of numerous half-pipe snowboard aerial acrobatics was collected using a Phantom 200Hz high speed video camera (VISION) from the bottom and centre of the half-pipe (Figure 12). High speed video footage was collected on only one aerial acrobatic manoeuvre throughout each run as the cameras used did not have the capacity to follow a rider’s progress through the half-pipe. High speed video footage was uploaded, digitized, and analysed by video analysis software (Swinger). Air-times quantified from 50Hz video footage were then validated against air-times quantified from high speed video footage.

Figure 12. The positioning of 200Hz High Speed Camera (HSC), a 50Hz digital camera, and the designated jump area (DJA) during a half-pipe snowboarding data collection session for the customization of wearable sensor technology to develop an automated performance feedback system suitable for calculation of air time and degree of rotation in routine training and competition environments. Image Heidi Barbay, Perisher Blue Ski Resort 2006.
2.3 Air Time Algorithm Development

Automatic quantification of air time may prove beneficial in assisting elite-level coaching and competition judging protocols. This can be calculated using quantitative data pertaining to air-time achieved during individual half-pipe snowboarding aerial acrobatic manoeuvres by using tri-axial accelerometer output. The raw unfiltered tri-axial accelerometer data obtained during a single half-pipe snowboard run produces a very distinct and repeatable pattern displaying elevated accelerations throughout the take off and landings associated with aerial acrobatic manoeuvres. Both half-pipe snowboarding run detection and air-time calculation was possible because of the rapid increases and decreases in acceleration in both the up/down and forward/back accelerometer axes. These rapid changes in acceleration occur when athletes progresses up, out of and eventually re-enter the vertical half-pipe transitions during the performance of aerial acrobatic manoeuvres. The quantification of air time associated with each aerial acrobatic manoeuvre using tri-axial accelerometer data is possible as a result of this pattern and the robust physical principle that the only force acting on an object whilst not in contact with the earth’s surface (assuming negligible wind resistance) is gravity ($9.8\text{m.s}^{-2}$ towards the earth’s surface). As a result, all accelerometers quantify approximately $0\text{g}$’s of force for the duration the athlete spends in the air. The properties of accelerometers are such that upon coming into contact with the earth’s surface following a period of air-time, there is a brief period of augmented activity and high force readings from which aerial acrobatic landings can be detected.

2.3.1 Subjects

Four members of the Australian Half-pipe snowboarding team were recruited to participate in this study. Their physical characteristics for age, height, weight and $\Sigma 7$ (sum of seven) skin folds were $22.18 \pm 6.93$ yrs, $1.70 \pm 7.80$ m, $74.30 \pm 15.50$ kg, $57.8 \pm 25.20$ mm (mean $\pm$ SD) respectively. Data collection was performed during southern hemisphere winter seasons (2005 – 2007) at Perisher Blue Ski Resort (altitude 1720 m) on the resort’s custom snowboard half-pipe (Length = 80.00m, Width = 18.0m, Height = 5.00m, Inclination = 15°). Experimental procedures were approved by the Ethics Committee of the Australian Institute of Sport on the 18th August 2005 (approval number 20050808).
2.3.2 Data Collection

A sensor (secured inside a padded bag) was attached via a strap to the lower back of each athlete (such that there was minimal movement of the sensor due to inertial forces), situated approximately 5cm to the left of the spine (Figure 13). As half-pipe snowboarding is a high risk sport where falls occur regularly, the attachment point was moved off the spine by approximately 5cm as a safety measure. The quantification of air time was focussed on signal processing of the patterns generated by inertial sensor data with gross reference to the rotation in the orthogonal axes. Data was collected from one individual athlete at a time during four routine Australian national team training sessions. Athletes were instructed to participate in training sessions as per normal routine, with no set number of runs or aerial acrobatics and no time limit imparted on each session. The only stipulation was that each athlete must designate a specific area of the half-pipe where they would regularly perform aerial acrobatic manoeuvres during their training. This section of the half-pipe (approximately 10m in width) was termed the designated jump area (DJA) and allowed a fixed high speed camera to collect data on manoeuvres attempted over that area (Figure 12). The protocol allowed athletes to train in routine fashion, eliminating changes to performance. As athletes trained, a panning digital video camera filmed all runs, a fixed high speed camera collected data from each manoeuvre attempted over the DJA, and tri-axial accelerometer data was collected for the duration of the entire session.

![Figure 13. The positioning of the inertial sensor unit on a snowboard athlete. A1, Accelerometer 1 (forward/backwards); A2, Accelerometer 2 (sideways); A3, Accelerometer 3 (upwards/downwards). Image: Obtained from Industrial Affiliates Program (IAP) student James Small from Griffith University and then altered to suit this thesis (Harding et al., 2007a).](image-url)
2.3.3 Signal Processing – Method One

Method One was initially developed together with Colin Mackintosh of the Applied Sensors Unit at the Australian Institute of Sport (Mackintosh et al., 2008). The rules generated for the calculation of air-times associated with individual aerial acrobatic manoeuvres during elite-level half-pipe snowboarding are provided below:

1. Tri-axial accelerometer data filtered with second order Butterworth Filter with 2.5Hz cut-off.
2. Calculation of a discriminant operator for event detection. This operator was termed Ac3Dif. Ac3Dif is determined by Equation 2 - 1:

   \[
   \text{Ac3Dif}_i = \left( \sum_{n=1}^{6} (A_{i-1}^n - A_{i+1}^n)^2 \right)^{1/2}
   \]

   Equation 2 - 1

   Where:

   \( i = \text{acceleration} \)
   
   \( t = \text{time} \)
   
   \( A = \text{accelerometer} \)

3. Detect threshold in Ac3Dif indicating end of air landing more than 0.7 secs after the end of previous air (0.7s is the average minimal time an athlete spends in contact with the snow surface after each half-pipe aerial acrobatic manoeuvre). Threshold defined as 5 out of 6 readings in a row that generate 0.5g data that is greater than the previous reading.

4. The ‘landing’ of the aerial acrobatic manoeuvre and hence the ‘end of an air’ (Air-End) is then the 2nd point of the group of 6 to account for joint loading.

5. A3 (upwards acceleration) data is used to detect the start of an aerial acrobatic manoeuvre (Air-Start).

6. Detect Air Start threshold. Threshold defined as 10 out of 20 contiguous readings that generate 0.03g data above previous reading. Threshold also corresponds to corresponding but opposite drop in A1 (forward acceleration). (Figure 12). Air Start must occur between 0.3s (minimum aerial acrobatic manoeuvre air time) and 2.0s (maximum aerial acrobatic air time) before Air End.

7. The start of an aerial acrobatic manoeuvre (Air-Start) aligns with a local peak value in a rolling 3 datum set.
8. Air time is difference between Air-End and Air-Start.

9. Air times between >0.90s and < 2.00s are valid. Air times >0.3 are noted as they are possibly a drop-in (period of air time where athlete drops into half-pipe course which is not considered an aerial acrobatic manoeuvre). If there is no air for the previous 5s then this must be a drop-in and therefore it is ignored.

2.3.4 Signal Processing - Method Two.

Subsequent analysis used a method developed in conjunction with Griffith University’s Centre for Wireless Monitoring And Applications’ James Small (Harding et al., 2007a). This method used multiple passes of the data. 1. Run Detection (Pre-Processor). 2. Air Time Detection. 3. Threshold Based Analysis.

The first pass was comprised of a sliding Fast Fourier Transform (FFT) window and power analysis which generated average power levels associated with tri-axial accelerometer data and thereby detecting individual runs. Power levels are raised during half-pipe snowboarding runs as a result of the substantial increases or decreases in acceleration levels throughout the performance of aerial acrobatic manoeuvres. Analysing entire runs for elevated levels of acceleration allowed run locations to be identified and run windows to be extracted. Evaluating each FFT window for frequencies ranging from 0.25Hz – 0.85Hz (as aerial acrobatic manoeuvres occur relatively rhythmically with a period of 1.2 - 4 seconds), provided a threshold based algorithm the capacity to then identify runs within the trace. The threshold for power was set relatively low to ensure no events were missed.

The second pass was comprised of a three state (maximum, minimum and transition) changeover system passed over the accelerometer data associated with a complete half-pipe snowboarding run. This transformed the raw accelerometer data within detected run windows into quantised values of 1’s 0’s and -1’s for high, transition and low states respectively. The technique then re-analysed the data on an airtime by airtime basis using a much smaller window which further improved accuracy. The high state threshold ratio (TH) was experimentally determined to be 0.25. The low state threshold (TL) was determined to be 0.3. Raw accelerometer data transformed into the high state quantised value of 1 gives a crude approximation of when the boarder was in the air and thus the beginning of an airtime. Raw accelerometer data transformed into the low state quantised value of -1 gives an approximation of when the athlete has landed back onto the half-pipe transition and is moving into the flat middle section of the half-pipe. A
transition state may include any values between these two threshold values, eliminating a large proportion of noise and movement not associated with air-times (Table 2).

Table 2. The first pass three state changeover system displaying the threshold level associated binary value, and state equation.

<table>
<thead>
<tr>
<th>Threshold</th>
<th>Binary Value</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>1</td>
<td>High = Data ≥ (max(data) + mean(data)) · TH</td>
</tr>
<tr>
<td>0.25 – 0.30</td>
<td>0</td>
<td>Transition = Low ≤ Data ≤ High</td>
</tr>
<tr>
<td>0.30 – -1.00</td>
<td>-1</td>
<td>Low = Data ≤ (min(data) − mean(data)) · TL</td>
</tr>
</tbody>
</table>

The third pass was focused on the durations of aerial acrobatic manoeuvres. Air-times are considered to start (from the quantised values 0 - 1) and air-times finish (from the quantised values 1 - 0). All components of a raw accelerometer data trace that meet these criteria are saved into an array (called ‘might’) whereby the ‘might’ array is then analysed for air-times that meet a specific duration. The duration of any component that meets the ‘might’ array criteria must therefore be of a duration between 0.8 – 2.2 seconds (a revised range that would cover most aerial acrobatic air-times completed by half-pipe snowboard athletes) to be considered a valid aerial acrobatic manoeuvre.

2.3.5 Statistical Analysis

Firstly, this study establishes that half-pipe snowboarding runs performed by instrumented athletes generate a distinct repeatable tri-axial accelerometer pattern that displays elevated accelerations throughout the take off and landings and a period of minimal force readings throughout the air time phase associated with aerial acrobatic manoeuvres (Figure 16). Secondly, this study allowed a criterion referenced (high speed video footage) validation of the air times quantified from 50Hz panning video footage (Table 16). Thirdly, this study provides a criterion-referenced (video based analysis) validation of the air-times associated with aerial acrobatics quantified by the accelerometer based practical methods presented in this study (Method 1, Table 17, Figure 17, 18; Method 2, Table 17, Figure 19, 20). All correlations are presented as correlation co-efficient ($r$) ± 95% confidence limits, p value ($p$), coefficient of determination ($r^2$), standard error of the estimate (SEE), sample size ($n$) and the predicted air-time regression equation ($PAT$). All mean data are presented as mean ± SD and all mean bias data is presented as mean ± 95% confidence limits. All mean bias calculations were performed using Excel spreadsheets (Hopkins, 2004). All
correlations ($r$), goodness of fit statistics ($r^2$), standard error of the estimates (SEE), and p-values ($P$) were calculated using SPSS 13.0 for Windows (Graduate Student Version, SPSS Inc, Chicago Illinois USA, www.spss.com). All graphs were generated using GraphPad Prism 4.01 (GraphPad Software Inc, La Jolla, CA, USA, www.graphpad.com). All confidence limits (CL) were performed using Excel spreadsheets (Hopkins, 2004) and were set at 95%. Significance was set at $p < 0.05$.

2.4 Degree of Rotation Algorithm Development

Air-time is only one component of successful half-pipe snowboarding performance. There is reason to believe that automatic quantification of degree of rotation may also prove beneficial in assisting elite-level coaching and competition judging protocols. This section builds upon the signal processing techniques associated with air time and describes how body mounted inertial sensors (specifically tri-axial rate gyroscopes) and signal processing can be used to automatically classify aerial acrobatic manoeuvres into four rotational groups (180°, 360°, 540° or 720° rotations).

2.4.1 Subjects

Ten Australian half-pipe snowboarders were recruited to participate in this study. Data collection was performed during southern hemisphere winter seasons (2005 – 2007) at Perisher Blue Ski Resort (altitude 1720 m) on the resort’s custom snowboard half-pipe (Length = 80.00m, Width = 18.0m, Height = 5.00m, Inclination = 15°). Data collection was performed during routine training sessions between 2005 and 2006. Experimental procedures were approved by the Ethics Committee of the Australian Institute of Sport on 18th August 2005 (ref: 20050808) and in accordance with Griffith University requirements, cleared under special review in January 2008 (ref: PES/01/08/HREC).

2.4.2 Data Collection

A sensor was attached to the lower back of each athlete, situated approximately 5cm to the left of the spine (Figure 13). As half-pipe snowboarding is a high risk sport where falls during attempted aerial acrobatic manoeuvres occur regularly, the attachment point was moved off the spine by approximately 5cm as a safety measure. Data were collected from one individual athlete at a time during routine national team training sessions. Athletes were instructed to participate in training sessions as per normal routine, with no set number of runs or aerial acrobatic manoeuvres and no time limit imparted on data collection session. Data collection therefore eliminated constriction or
alteration of performance. Panning digital video filmed half-pipe runs and tri-axial accelerometer / rate gyroscope data was collected for the duration of each data collection session. The protocol allowed athletes to train in routine fashion and eliminated any constriction or alteration of their performance. As athletes underwent their training session a panning digital video camera filmed complete half-pipe runs, and tri-axial accelerometer data was collected for the duration of the training session.

2.4.3 Signal Processing – Method One

This study focused upon aerial acrobatics performed predominantly around a single axis (yaw) resulting in what are termed by the snowboard community as ‘flat spins or rotations’ (Figure 14). These rotations are essentially void of inversion and as such simplify classification. Signal processing was developed with Colin Mackintosh of the Applied Sensors Unit at the Australian Institute of Sport (Harding et al., 2008a; Mackintosh et al., 2008).

Figure 14. Air-time is only one component of successful half-pipe snowboarding performance. Body mounted inertial sensors (specifically tri-axial rate gyroscopes) and numerical integration of the orthogonal axes (i, yaw; j, pitch; k, roll) can be used to automatically classify aerial acrobatic manoeuvres into four rotational groups (180°, 360°, 540° or 720° rotations). This method only works for aerial acrobatics performed predominantly around a single axis (yaw) resulting in what are termed by the snowboard community as ‘flat spins’. Future research will focus on a more detailed classification system with the capacity to generate trick names from inertial sensor data. Professional snowboarder competing at the Burton Open Australian Half-Pipe Championships. Image: Heidi Barbay, Perisher Blue Ski Resort, Australia 2008.
Classification of aerial acrobatics performed during elite half-pipe snowboarding runs was achieved using integration by summation. Angular velocity ($\omega^i, j, k$) quantified by tri-axial rate gyroscopes was integrated over time ($t = 0.01s$) to provide angular displacements ($\theta^i, j, k$). Absolute angular displacements for each orthogonal axes ($i, j, k$ where $i = $ yaw, $j = $ pitch, $k = $ roll) were then accumulated over the duration of an aerial acrobatic manoeuvre to provide the total angular displacement achieved in each axis over that time period. The total angular displacements associated with each orthogonal axes were then summed to calculate a dimensionless composite rotational parameter called Air Angle (AA). The mathematical representation (Equation 2 - 2) of this tri-axial rate gyroscope signal processing method focussed on to classifying acrobatic manoeuvres performed during half-pipe snowboarding is provided below.

1. Rate gyroscope data (providing angular velocity) was sampled at 100Hz such that $t= 0.01s$ and additionally in 3 orthogonal axes ($i, k, j$); of which one single axis of rotation is denoted by $j$ in the following mathematical integration.

2. $N =$ number of sample points associated with the air-time of one aerial acrobatic manoeuvre.

3. $AT =$ air-time measured in seconds (calculated using a previously documented signal processing technique using acceleration.

4. $AA =$ Air Angle; a measure of cumulative displacement achieved in all three orthogonal axes for the duration of aerial acrobatics.

$$AA = \sum_{n=1}^{2} \sum_{j=1}^{j} \omega_k \Delta t$$

Where:

$AA =$ air time

$n =$ angular rate (deg.$s^{-1}$)

$t =$ time

$\omega =$ rate gyroscope

$\Delta t =$ sample rate
2.4.4 Statistical Analysis

This study allowed a criterion-referenced (video based analysis in combination with ‘practice community’ rules for degree of rotation classification) validation of the degree of rotation classifications associated with 216 aerial acrobatic manoeuvres calculated by the tri-axial rate gyroscope based practical method presented in this study (Figure 21, Figure 22, Table 18). Difference between the mean Air Angles measured for each of the four rotational groups (180°, 360°, 540°, 720°) was evaluated using a One-way ANOVA (Figure 22). All statistics were calculated using SPSS 13.0 for Windows (Graduate Student Version, SPSS Inc, Chicago Illinois USA, www.spss.com). All confidence limits (CL) were performed using Excel spreadsheets (Hopkins, 2004). All confidence limits were set at 95% and statistical significance was set at $p < 0.05$. All graphs were generated using GraphPad Prism 4.01 (GraphPad Software Inc, La Jolla, CA, USA, www.graphpad.com).

2.5 Integration Into Elite Sport

With the capacity to automatically calculate objective information on the strongest key performance indicators associated with half-pipe snowboard competition success, we conducted an invitational concept competition, the 2007 Australian Institute of Sport (AIS) Micro-Tech Pipe Challenge. This competition was designed to evaluate whether the snowboard community would embrace a competition where results were in part determined by automated objectivity, explore the practical, logistical and technical challenges associated with conducting such an event, evaluate the relationship between subjective judging and results predicted from objective information to see if prior research had ecological validity and explore the utility of incorporating micro-technology to enhance the “fairness” of judging world class snowboard athletes. Based on previous research findings established by this study we constructed a snowboard competition that would require athletes to compete whilst instrumented with inertial sensors.

2.5.1 Subjects

Ten elite-level male Australian half-pipe snowboarders were recruited and ultimately volunteered to participate in this study. Data collection was performed during the southern hemisphere winter season of 2007 on Monday 30th July at Perisher Blue Ski Resort (altitude 1720 m) on the resort’s custom snowboard half-pipe (Length = 80.00m,
Width = 18.0m, Height = 5.00m, Inclination = 15°). Environmental and snow temperatures for this event was 7°C and 0.4°C respectively. Data collection was performed during a total of 50 competition runs. Experimental procedures were approved by the Ethics Committee of the Australian Institute of Sport on 18th August 2005 (ref: 20050808) and in accordance with Griffith University requirements, cleared under special review in January 2008 (ref: PES/01/08/HREC).

2.5.2 Equipment And Signal Processing

Implementation of sensors developed in house comprising of one tri-axial accelerometer (100Hz, ± 6g) and one tri-axial rate gyroscope (100Hz ± 1200 deg s\(^{-1}\), 20.94 rad s\(^{-1}\)) were used throughout data collection and the associated competition. Sensors were attached to the lower back of each athlete, situated approximately 5cm to the left of the spine as previously described and as shown in Figure 13. Raw data was stored on board the sensor unit for the duration of data collection process, sampled and analysed post collection by a computer software suite developed in house (Mackintosh et al., 2008). Accelerometer components underwent 2-point static calibration in three orthogonal axes (up/down, forward/back and left/right) aligning each axes of sensitivity with and against the direction of gravity. Rate gyroscope components underwent a 2-point calibration integrating angular velocity over time throughout 0 and 90 degrees in three orthogonal axes (yaw, pitch, roll) prior to each data collection session (Green & Krakauer, 2003). There was only small short term drift associated with this gyroscope calibration method and the validation studies associated with rate gyroscope processing conducted in this thesis show that it is verified. Panning video footage of each half-pipe run was collected using a Sony 3CCD 50Hz digital video camera (Sony, TRV950E, Tokyo Japan, www.sony.com) from the bottom and centre of the half-pipe (Figure 9) to provide feedback on style and execution to athletes and to serve as a backup method of key performance indicator calculation in the advent of failure of any of the sensors. Data was processed with previously documented methods of automated air-time calculation and degree of rotation classification in order to automatically and objectively assess these sport specific key performance variables during an elite-level competition environment. Sensors were switched on and began collecting data at the beginning of the competition (8.30am) and were switched off and ceased data collection immediately after the competitions’ completion (11.00am). All objective data derived from micro-technology sensors was processed immediately following the competition and required approximately two-hours to generate a complete assessment of all objective information.
related to air-time and degree of rotation.

### 2.5.3 Competition Format and Judging

The purpose of this competition was to compare traditional subjective judging results with those predicted using purely objective data with no reference to style or execution. The competition also focussed on an initial integration of automated objectivity into elite half-pipe snowboarding by awarding three separate prizes based on objective information judged solely by micro-technology. Competition performances judged purely by objective measures were 1) Highest average air-time. 2) Highest average degree of rotation. 3) Highest individual air-time. A World Cup and Olympic Games snowboard judge was appointed as the sole judge for the traditional subjective judging component associated with this competition. Athletes were awarded an overall impression score out of 10 for each competition routine by this judge. Objective data was provided by post-event processing of micro-technology outputs. The athletes themselves were also asked immediately following the completion of the event to provide (anonymously) their selections associated with the top 5 athletic performances to award an athlete judged best rider award. Athletes were provided with a 30 minute warm up period prior to the start of the competition. All athletes had access to ‘over-snow’ transport (skidoo) providing them quick access to the top of the half-pipe following each warm up and competition run. Athletes were allowed three runs to contest the traditional subjective judging component of the competition, the objective judging components of highest average air-time and highest average degree of rotation and the athlete judged best rider component. The objectively judged highest individual air-time was decided with an additional two run format that immediately followed the main competition allowing each athlete the chance to perform only one aerial acrobatic manoeuvre per-run with the specific instruction to complete straight airs focussed on as much amplitude and air-time as possible.

### 2.5.4 Predicted Scoring Using Objective Data

Predicted scores and rankings were calculated using objective data in a multiple regression prediction equation based on previously established weightings (Equation 2 – 3, Table 6).
\[ PS = 11.42AAT + 0.013ADR - 2.223 \]  

Equation 2 - 3

\textit{Where:}

\[ PS = \text{predicted score} \]
\[ AAT = \text{average air time} \]
\[ ADR = \text{average degree of rotation} \]

Previous established weightings were derived from a video-based analysis of an elite-level event conducted on the same half-pipe almost a year earlier (Burton Australian Open 2006). The prediction equation included the key performance variables of average air-time and average degree of rotation and was determined by multiple linear regression (Table 6). Each run in the 2006 Burton Open event was scored out of 30 and as the 2007 AIS Micro-Tech Challenge event was scored out of a total 10 available points. The predicted score generated by the aforementioned regression was subsequently divided by a factor of 3. Data associated with predicted scores and subjectively judged scores were then examined to determine retrospectively if rankings would be any different if entire scores were established using automated objectivity.

2.5.5 Statistical Analysis

This study allowed a criterion (subjectively judged scores) referenced validation of predicted competition scores (objective practical measure) associated with 18 cleanly completed runs performed during the AIS Micro-Tech Pipe Challenge. Cleanly completed runs were deemed to be competition aerial acrobatic routines performed without major mistakes such as falls, stops, placing hands onto snow surface upon landing and associated losses of momentum. All correlations are presented as correlation co-efficient \((r) \pm 95\% \text{ confidence limits}, p \text{ value } (p), \text{ coefficient of determination } (r^2), \text{ standard error of the estimate } (SEE) \text{ and sample size } (n)\). All mean bias results are presented as mean bias \(\pm 95\% \text{ confidence limits}\). All correlations \((r)\), goodness of fit statistics \((r^2)\), standard error of the estimates \((SEE)\), and p-values were calculated using SPSS 13.0 for Windows (Graduate Student Version, SPSS Inc, Chicago Illinois USA, www.spss.com). All confidence limits (CL) and mean bias calculations were performed using excel spreadsheets provided by Hopkins, 2004. All confidence limits were set at 95\% and statistical significance was set at \(p < 0.05\). Stacked graphs were generated using GraphPad Prism 4.01 (GraphPad Software Inc, La
2.6 Sociological Impact

The proposed introduction of a competition judging system based solely or partially upon objective information into half-pipe snowboarding (a sport habitually focused on athletic individuality and freedom of expression) will no doubt provide sport scientists (as implementers) and the ‘practice community’ (those affected) with challenges. Perhaps the most significant aspect of change in sport is that any such action can dictate the future of a sport in a way that makes reversing such changes very difficult (Miah, 2000). Technology often has additional and unintended consequences and possesses the capacity to effect change beyond its original purpose (Tenner, 1996; Miah, 2000).

As argued by Miah (2000), changes, technological or otherwise, should be preceded with some discussion about what future is sought for a specific sport and thus, where limits might be drawn on the changes. Defining who should determine the nature of a sport ought not to be a difficult issue. It seems imperative to ensure practicing communities are allowed to articulate their interests in forums that convey influence (Morgan, 1994). This study is a result of action based research involving a progressive partnership ideology with the ‘practice community’. It has allowed the snowboarding community a forum to describe its perceptions on the impact of future automated judging concepts and possible technological change within their sporting discipline.

2.6.1 Coaches And Athletes

The population for this study was selected by theoretical sampling and included eight subjects (six elite athletes and two national coaches). Subjects’ level of experience in elite half-pipe snowboard competition ranged from 4 – 12 years. As all subjects were of Australian nationality, this was accepted as a limitation. Future studies would benefit by increasing sample size and evaluating international ‘practice community’ members. Subjects read ‘information to participant’ and signed ‘informed consent’ forms prior to taking part. Experimental procedures were approved by the Ethics Committee of the Australian Institute of Sport on 17th August 2006 (approval number 20060807).

The results of this study were obtained by interviewing subjects on their perceptions of how technological change would impact on the culture of their sport. The nature of the
research questions (Table 3) directed the data collection process be in-depth and consistent with an inductive analysis (Smith & Shilbury, 2004). In-depth interviews were selected as the most suitable data collection tool. Subjects were interviewed between 16th and 20th October 2006 at the Australian Institute of Sport (AIS). Interviews were semi-structured, involved posed, open ended questions, were recorded on video tape, and later transcribed word-for-word. Each subject was interviewed individually for approximately 20-45 minutes. All subjects approached for this interview accepted.

Table 3. A list of the open ended interview questions posed to elite-level coaches and athletes. Interview questions were focussed on the perception of elite-level coaches and athletes on the impact of the automated performance assessment concepts and possible technological change within half-pipe snowboarding posed by this study. The nature of the research questions posed to coaches and athlete directed the data collection process be in-depth and consistent with an inductive analysis (Smith & Shilbury, 2004). In-depth interviews were selected as the most suitable data collection tool.

1. How long have you been involved in competitive snowboarding?

2. How long have you been involved in competitive snowboarding at the elite level?

3. Can you please comment on the accuracy of the current judging system used within half-pipe snowboarding?

4. What are the strengths and weaknesses of the current judging system?

5. How do you think the judging system could be improved from its current status?

6. Do you think it’s possible to electronically judge an elite level half-pipe snowboarding competition using objective information on air time and degree of rotation?

7. What would be the advantages/ disadvantages of this approach?

8. Do you think jump height associated with aerial acrobatics should be awarded?

9. How do you think automatic electronic judging using objective information would be
perceived by the snowboarding community?

10. Do you think this concept could work at club level events, with emerging athletes?

11. How do you think a concept such as this should be introduced into the snowboarding community?

12. Do you feel like having access to this type of technology on a day-to-day basis could benefit your performance as an athlete?

13. Do you think the introduction of this concept would provide a competitive advantage to Australian snowboard athletes and a cultural advantage to Australian snowboarding in general?

14. What do you think would be the best way to introduce this concept into competitive snowboarding?

15. Are there any other comments you would like to make on this concept?

Interview transcripts were first examined to gain general familiarity. Dominant themes were noted and these formed categories. These categories became the codes by which transcripts were further interpreted. Manual coding was undertaken with a hierarchical three stage process (Strauss & Corbin, 1990) beginning with identification of ‘open’ codes. Open codes provided a broad set of cultural categories with which to conduct subsequent reduction. ‘Axial’ coding subsequently divided each open code into several axial codes which reflected cultural dimensions employed to measure the perception of the ‘practice community’ to specific issues. Axial codes were then divided into ‘selective’ codes. Selective codes provided researchers capacity to highlight the content of specific cultural dimensions (Smith & Shilbury, 2004). Labels were selected that best described conceptual contents of each code however; it is worth noting that labels represent researcher interpretation of content (Smith & Shilbury, 2004). The number of occasions selective codes were mentioned revealed the significance of each sub-dimension to major cultural themes. A reliability measure used by Smith & Shilbury
(2004) was adopted by this study. Where Smith and Shilbury calculated an inter-
researcher reliability score, this study used one researcher undertaking a test-retest
analysis on each interview one week apart hence; an intra-researcher reliability score
was calculated. This study generated a satisfactory intra-researcher reliability level
greater than 90%, as recommended by Miles & Huberman (1994).

2.6.2 World Cup Judges

The population for this study was selected by theoretical sampling and included 16
elite-level (professional level, FIS World Cup and Winter Olympic Games) half-pipe
snowboarding judges. In light of FIS attempts to construct judging panels comprised of
English speaking judges from a variety of nations to minimise potential national bias,
the population sample for this study included elite-level judges from the following
nations; Australia (n = 2), Spain (n = 2), Czech Republic (n = 1), Sweden (n = 4), New
Zealand (n = 1), Netherlands (n = 1), United States of America (n = 2), Canada (n = 1),
Slovenia (n = 1), Poland (n = 1). Subjects’ level of experience in judging elite-level
half-pipe snowboard competition ranged from 4 – 16 years.

The results of this study were obtained by interviewing subjects on the impact of
technological change on the culture of their sport. In-depth interviews were selected as
the most suitable data collection tool because of the rich data that they provide. As a
result of the near impossibility of conducting interviews with each international subject
in person, subjects were interviewed by email correspondence between 27th January
2007 and 25th February 2008. Interviews were structured, conducted via email
correspondence, involved posed, open ended questions (Table 4), and responses were
written by each subject. Not all subjects approached for this interview accepted. 16 out
of 30 subjects approached for this interview accepted and provided anonymous
responses.

Table 4. A list of the open ended interview questions posed to elite level World Cup half-pipe
snowboard judges. Interview questions were focussed on the perception of elite-level judges on
the impact of the automated performance assessment concepts and possible technological
judging concepts within half-pipe snowboarding posed by this study. The nature of the research
questions posed to elite level World Cup half-pipe snowboard judges directed the data
collection process be in-depth and consistent with an inductive analysis (Smith & Shilbury,
2004). In-depth interviews were selected as the most suitable data collection tool.

1. Name. (Note, name will not be published, all participants will remain anonymous).

2. What is your judging experience (i.e. How long have you been a half-pipe snowboard
3. Comment on the following statement. That elite-level half-pipe snowboarding competition will eventually suffer from what has been termed an underlying ‘self annihilating teleology’. Many sports seem to display this as they progress. By this I mean that it is possible increased numbers of half-pipe snowboarding athletes will ultimately achieve ‘optimal performance’, thereby outgrowing the structure of the sport and its current judging protocol (i.e. How are you expected to judge a competition when the top 10 – 20 riders can all complete the most difficult tricks and do it with the same high level of execution). When this happens, sports are often forced to adopt altered performance assessment methods, equipment changes, or altered game rulings to again separate similarly capable athletes.

4. Read this section as it is a brief summary of the technologically based performance assessment concept currently in development for half-pipe snowboarding.

I can currently accurately measure exact air-time (AT) and degree of rotation (DR) using micro-technology during half-pipe snowboarding runs. The idea is to provide objective assistance to judges in elite-level competition and retain a certain level of subjective assessment of overall style and run execution. I understand height above the lip would be more appropriate however; at this point in time I do not have the capacity to measure it. From analysing judging at World Cup, Olympic Games, and national level events, I have also shown that an athlete’s total score relates well to air–time and degree of rotation (even though it is not objectively measured by judging panels). Here are a few definitions of the variables I can measure using technology during half-pipe snowboarding.

Air-time (AT) is measured in seconds and reflects the amount of time the athlete spends in the air during a half-pipe snowboarding routine. Air-time begins the first moment there is no longer contact between the snowboard and the snow and ends the moment any part of the snowboard comes in contact with the snow following an attempted aerial acrobatic manoeuvre.

Total air-time (TAT) is measured in seconds and calculated by adding together all recorded air-times (typically 6 - 8) during a half-pipe snowboard run.

Average air-time (AAT) is also measured in seconds and is calculated by dividing total air-time (TAT) by number of by the total number of aerial acrobatic manoeuvres completed throughout the duration of a half-pipe snowboarding run.
Degree of rotation (DR) is measured in degrees and reflects the approximate amount of rotation an athlete completes in the air during execution of half-pipe snowboarding aerial acrobatic manoeuvres (i.e. 360, 540, 720 spins).

Total degree of rotation (TDR) is measured in degrees and calculated by adding together all recorded rotations (typically 6 - 8) during a half-pipe snowboard run.

Average degree of rotation (ADR) is also measured in degrees and is calculated by dividing total degree of rotation (TDR) by the total number of aerial acrobatic manoeuvres completed throughout the duration of a half-pipe snowboarding run.

5. In terms of total air-time, average air-time, total degree of rotation and average degree of rotation, which ones do you think has the most influence in your scoring of athletes in half-pipe snowboarding competition?

6. Which of the following variables; total air-time (TAT), average air-time (AAT), total degree of rotation (TDR), average degree of rotation (ADR) would you include in a more objective judging protocol (you can pick only two of these variables, one associated with air-time and one associated with degree of rotation)?

7. Do you think the capacity to provide you (elite-level half-pipe judges) with some objective information (like the variables mentioned above) would assist in your efforts to reliably judge elite-level half-pipe competition?

8. How do you think such a concept would be perceived by the elite-level half-pipe snowboarding athlete community?

9. Are there any other comments you would like to make on this concept?

10. Could you please write a brief statement that you have read the information to participants and agree for your responses to be compiled and published in a scientific journal article (your responses would remain anonymous in the publication of grouped responses).

Interview transcripts were first examined to gain general familiarity. Dominant themes were noted and these formed categories. These categories became the codes by which
transcripts were further interpreted. Manual coding was undertaken with a hierarchical three stage process (Strauss & Corbin, 1990) beginning with identification of ‘open’ codes. Open codes provided a broad set of categories with which to conduct subsequent reduction. ‘Axial’ coding subsequently divided each open code into several axial codes which reflected cultural dimensions employed to measure the perception of the ’practice community’ to specific issues. Axial codes were then divided into ‘selective’ codes. Selective codes provided researchers with the capacity to highlight the content of specific cultural dimensions cultural dimensions (Smith & Shilbury, 2004). Labels were selected that best described conceptual contents of each code however; it is worth noting that labels represent researcher interpretation of content (Smith & Shilbury, 2004). The number of occasions selective codes were mentioned revealed the significance of each sub-dimension to major cultural themes. A reliability measure used by Smith & Shilbury (2004) was adopted by this study. Where Smith and Shilbury calculated an inter-researcher reliability score, this study used one researcher undertaking a test-retest analysis on each interview one week apart hence; an intra-researcher reliability score was calculated. This study generated a satisfactory intra-researcher reliability level greater than 90%, as recommended by Miles & Huberman (1994).

All subjects sampled were elite-level competition judges and this was accepted as a limitation in assessing a more generalised ‘practice community’ perception. The intent however for this particular study, was to assess this cultural group specifically and results therefore provide insight from an elite judging standpoint and not from the general community. Future studies would benefit from increased sample size and evaluating other international ‘practice community’ members including athletes and coaches in addition to competition judges. The subjects read the ‘information to participant’ forms and signed ‘informed consent’ forms prior to taking part. Experimental procedures were approved by the Ethics Committee of the Australian Institute of Sport on 17th August 2006 (ref: 20060807) and in accordance with Griffith University requirements, cleared under special review in January 2008 (ref: PES/01/08/HREC).
2.7 References


3 RESULTS

3.1 Key Performance Indicators

The findings in this section have been generated from elite-level half-pipe snowboarding competitions, including a Winter Olympic Games, over a three year period. The results are novel and practically relevant to elite-level half-pipe snowboarding performance and have significant application in training and competition performance assessment. This study has established that AAT and ADR alone correlate strongly to subjectively judged competition scores and that when these two individual KPI’s are combined using multiple regression, they can account for a large component of half-pipe snowboard competition success. For the most part, there are key differences (with at least moderate to very large effect sizes) in AAT and ADR performance between those athletes that are successful in elite half-pipe snowboarding competition and those that are not. The performance levels associated with elite-level half-pipe snowboarding are additionally undergoing a continual state of evolution, with athletic performance of AAT and ADR showing a longitudinal increase over three years in men’s competitions. The same trend however was not established for women’s performances, suggesting women’s half-pipe snowboarding performance was at the time an embryonic entity, theorised to be resultant of an emergent competitor base. The strength of relationships between these sport specific KPI’s and competition success, the smallest worthwhile changes in AAT and ADR performance required to increase success in completion, the longitudinal increase in AAT and ADR performance, and the gold standard performance levels established by this study can be used by coaches, athletes and judges to exploit the factors most highly associated with success. For coaches and athletes who did not perform well in these competitions, it is believed the objective performance information established in this study would provide specific objective training targets and preparation protocols for future competitions. For competition judges, the objective information presented in this study has the potential to assist the current subjective performance assessment protocols and minimise any potential bias and judging corruption.

3.1.1 Burton Open Australian Half-Pipe Championships

During the three years we assessed key performance indicators in the Burton Open Australian Half-Pipe Championships, average air time and average degree of rotation...
were the strongest individual key performance indicators when correlated to subjectively judged scores (Table 5). Individually, average air time alone explains 51 - 56% of the shared variance in subjectively judged scores and average degree of rotation alone explains 52 - 68% of the shared variance in subjectively judged scores in the men’s competitions. Apart from one instance (women’s AAT performance in 2006), average air time alone explains 69 – 83% of the shared variance in subjectively judged scores and average degree of rotation alone explains 65 - 75% of the shared variance in subjectively judged scores in the women’s competitions.

Table 5. Linear regression analysis of strongest individual key performance indicators when correlated to subjectively judged scores during Burton Open Australian Half-Pipe Challenge.

<table>
<thead>
<tr>
<th>Year</th>
<th>KPI</th>
<th>r</th>
<th>CL</th>
<th>p</th>
<th>r²</th>
<th>SEE</th>
<th>n</th>
<th>Predicted Score Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>AAT(s)</td>
<td>0.74</td>
<td>0.18</td>
<td>&lt;0.001</td>
<td>0.54</td>
<td>3.91</td>
<td>28</td>
<td>PS = 20.62AAT – 7.92</td>
</tr>
<tr>
<td></td>
<td>ADR(°)</td>
<td>0.83</td>
<td>0.13</td>
<td>&lt;0.001</td>
<td>0.68</td>
<td>3.25</td>
<td>28</td>
<td>PS = 0.025ADR + 4.83</td>
</tr>
<tr>
<td>2007</td>
<td>AAT(s)</td>
<td>0.75</td>
<td>0.12</td>
<td>&lt;0.001</td>
<td>0.56</td>
<td>9.69</td>
<td>57</td>
<td>PS = 64.53AAT – 23.35</td>
</tr>
<tr>
<td></td>
<td>ADR(°)</td>
<td>0.72</td>
<td>0.13</td>
<td>&lt;0.001</td>
<td>0.52</td>
<td>10.16</td>
<td>57</td>
<td>PS = 0.071ADR + 21.72</td>
</tr>
<tr>
<td>2008</td>
<td>AAT(s)</td>
<td>0.71</td>
<td>0.19</td>
<td>&lt;0.001</td>
<td>0.51</td>
<td>10.11</td>
<td>30</td>
<td>PS = 67.06AAT – 24.49</td>
</tr>
<tr>
<td></td>
<td>ADR(°)</td>
<td>0.76</td>
<td>0.16</td>
<td>&lt;0.001</td>
<td>0.57</td>
<td>9.43</td>
<td>30</td>
<td>PS = 0.076ADR + 21.11</td>
</tr>
<tr>
<td>Women</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>AAT(s)</td>
<td>0.16</td>
<td>0.52</td>
<td>0.592</td>
<td>0.25</td>
<td>4.92</td>
<td>14</td>
<td>PS = 6.77AAT +12.79</td>
</tr>
<tr>
<td></td>
<td>ADR(°)</td>
<td>0.81</td>
<td>0.22</td>
<td>0.001</td>
<td>0.65</td>
<td>2.95</td>
<td>14</td>
<td>PS = 0.043ADR + 6.59</td>
</tr>
<tr>
<td>2007</td>
<td>AAT(s)</td>
<td>0.91</td>
<td>0.07</td>
<td>&lt;0.0001</td>
<td>0.83</td>
<td>9.27</td>
<td>28</td>
<td>PS = 89.08AAT - 24.98</td>
</tr>
<tr>
<td></td>
<td>ADR(°)</td>
<td>0.85</td>
<td>0.12</td>
<td>&lt;0.0001</td>
<td>0.73</td>
<td>11.78</td>
<td>28</td>
<td>PS = 0.235ADR – 14.52</td>
</tr>
<tr>
<td>2008</td>
<td>AAT(s)</td>
<td>0.83</td>
<td>0.23</td>
<td>&lt;0.0001</td>
<td>0.69</td>
<td>13.39</td>
<td>12</td>
<td>PS = 116.71AAT – 54.63</td>
</tr>
<tr>
<td></td>
<td>ADR(°)</td>
<td>0.87</td>
<td>0.19</td>
<td>&lt;0.0001</td>
<td>0.75</td>
<td>12.01</td>
<td>12</td>
<td>PS = 0.170ADR + 4.25</td>
</tr>
</tbody>
</table>

KPI, Key performance indicator; AAT, Average Air Time; ADR, Average Degree of Rotation; s, seconds; °, degrees. All correlations are presented as correlation coefficient (r) ± 95 per cent confidence limits (CL), P-value (p), coefficient of determination (r²), standard error of the estimate (SEE), sample size, number of runs analysed (n); predicted score regression equation (PS). Confidence limits were set at 95 per cent, statistical significance set at P <0.05.

When the two strongest objective, individual key performance indicators AAT and ADR are combined using a multiple regression (enter method) they explain approximately 77%, 77%, and 71% of the shared variance in subjectively judged scores during the men’s competitions and approximately 80%, 94% and 86% of the shared variance in subjectively judged scores during the women’s competitions at the Burton Open Australian Half-Pipe Championships in 2006, 2007, and 2008 respectively (Table...
The large amount of shared variance explained by purely objective measures in this event has applications for coaches, athletes and judges in training and competition performance assessment.

**Table 6.** Multiple linear regression analysis (enter method) of the combination of strongest individual key performance indicators AAT and ADR and their relationship to subjectively judged scores during the Burton Open Australian Half-pipe Championships (2006 – 2008). Strongest individual key performance indicators determined by strength of individual correlation to scores during each competition (Table 1).

<table>
<thead>
<tr>
<th>Year</th>
<th>KPI</th>
<th>( r )</th>
<th>CL</th>
<th>( p )</th>
<th>( r^2 )</th>
<th>SEE</th>
<th>( n )</th>
<th>Predicted Score Regression Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Men</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>AAT/ADR</td>
<td>0.88</td>
<td>0.11</td>
<td>&lt;0.001</td>
<td>0.77</td>
<td>2.82</td>
<td>28</td>
<td>( PS = 11.42AAT + 0.013ADR - 2.223 )</td>
</tr>
<tr>
<td>2007</td>
<td>AAT/ADR</td>
<td>0.88</td>
<td>0.06</td>
<td>&lt;0.001</td>
<td>0.77</td>
<td>7.16</td>
<td>57</td>
<td>( PS = 46.86AAT + 0.048ADR - 27.06 )</td>
</tr>
<tr>
<td>2008</td>
<td>AAT/ADR</td>
<td>0.84</td>
<td>0.12</td>
<td>&lt;0.001</td>
<td>0.71</td>
<td>7.95</td>
<td>30</td>
<td>( PS = 40.82AAT + 0.053ADR - 21.06 )</td>
</tr>
<tr>
<td></td>
<td>Women</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>AAT/ADR</td>
<td>0.90</td>
<td>0.13</td>
<td>&lt;0.001</td>
<td>0.80</td>
<td>2.32</td>
<td>14</td>
<td>( PS = 17.49AAT + 0.048ADR - 14.88 )</td>
</tr>
<tr>
<td>2007</td>
<td>AAT/ADR</td>
<td>0.97</td>
<td>0.03</td>
<td>&lt;0.001</td>
<td>0.94</td>
<td>5.69</td>
<td>28</td>
<td>( PS = 60.33AAT + 0.122ADR - 34.05 )</td>
</tr>
<tr>
<td>2008</td>
<td>AAT/ADR</td>
<td>0.93</td>
<td>0.11</td>
<td>&lt;0.001</td>
<td>0.86</td>
<td>9.51</td>
<td>12</td>
<td>( PS = 63.04AAT + 0.110ADR - 38.78 )</td>
</tr>
</tbody>
</table>

KPI, Key performance indicator; AAT, Average Air Time; ADR, Average Degree of Rotation; AAT/ADR, Combination of AAT and ADR by multiple linear regression (enter method). All correlations are presented as correlation coefficient (\( r \)) ± 95 per cent confidence limits (CL), P-value (\( p \)), coefficient of determination (\( r^2 \)), standard error of the estimate (SEE), sample size, number of runs analysed (\( n \)); predicted score regression equation (PS). Confidence limits were set at 95 per cent, statistical significance set at \( P <0.05 \).

A key aspect of this study was the magnitude of difference in performance between athletes achieving top three final rankings and those athletes achieving final rankings outside the top three finish places. The differing levels of performance in terms of average air time and average degree of rotation between those groups are shown in Table 7. Athletes achieving top three final rankings routinely perform better in terms of average air time and average degree of rotation than those athletes who achieve final rankings outside the top three finish places. Although not all mean differences are statistically significant, the magnitude of difference between the means of average air time and average degree of rotation between these two groups is for the most part moderate to very large. The relative importance of average air time and average degree of rotation performance in elite-level half-pipe snowboarding competition is believed to provide a basis for developing and implementing individual athlete strategy, reliable assessment of performance progression in training, team selection criteria and additionally, enhanced competition judging protocols.
Table 7. Absolute and magnitude-based differences between performance of AAT and ADR by athletes who achieve top three final rankings and those that do not. Data presented as AAT (s) or ADR (°), (Mean ± SD), Magnitude of difference (reported as mean difference ± 95% CL, significance, effect size ± 95% CL, and rating). Positive effect size value indicates athletes achieving top three final rankings perform better in terms of AAT or ADR than those achieving final rankings outside the top three.

<table>
<thead>
<tr>
<th>KPI</th>
<th>Year</th>
<th>Top 3</th>
<th>Outside Top 3</th>
<th>Mean Diff</th>
<th>p</th>
<th>Effect Size</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men</td>
<td>2006</td>
<td>1.39 ± 0.10</td>
<td>1.20 ± 0.20</td>
<td>0.19 ± 0.10</td>
<td>0.050</td>
<td>1.20 ± 0.81</td>
<td>Large</td>
</tr>
<tr>
<td></td>
<td>2007</td>
<td>1.44 ± 0.22</td>
<td>1.28 ± 0.16</td>
<td>0.16 ± 0.36</td>
<td>0.080</td>
<td>0.71 ± 1.65</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>2008</td>
<td>1.52 ± 0.06</td>
<td>1.34 ± 0.15</td>
<td>0.18 ± 0.10</td>
<td>0.002</td>
<td>1.52 ± 0.86</td>
<td>Large</td>
</tr>
<tr>
<td></td>
<td>2006</td>
<td>729.00 ± 140.15</td>
<td>466.00 ± 166.65</td>
<td>263.00 ± 175.40</td>
<td>0.003</td>
<td>1.63 ± 1.09</td>
<td>Large</td>
</tr>
<tr>
<td></td>
<td>2007</td>
<td>726.75 ± 48.40</td>
<td>537.00 ± 132.52</td>
<td>189.75 ± 72.38</td>
<td>0.007</td>
<td>1.87 ± 0.71</td>
<td>Large</td>
</tr>
<tr>
<td></td>
<td>2008</td>
<td>742.50 ± 93.67</td>
<td>597.52 ± 144.38</td>
<td>144.98 ± 143.1</td>
<td>0.066</td>
<td>1.14 ± 1.13</td>
<td>Moderate</td>
</tr>
<tr>
<td>Women</td>
<td>2006</td>
<td>1.16 ± 0.13</td>
<td>1.09 ± 0.10</td>
<td>0.07 ± 0.10</td>
<td>0.281</td>
<td>0.56 ± 1.15</td>
<td>Small</td>
</tr>
<tr>
<td></td>
<td>2007</td>
<td>1.10 ± 0.12</td>
<td>0.79 ± 0.21</td>
<td>0.31 ± 0.17</td>
<td>0.003</td>
<td>1.76 ± 0.97</td>
<td>Large</td>
</tr>
<tr>
<td></td>
<td>2008</td>
<td>1.14 ± 0.06</td>
<td>0.84 ± 0.06</td>
<td>0.30 ± 0.08</td>
<td>&lt;0.001</td>
<td>4.69 ± 1.25</td>
<td>Infinite</td>
</tr>
<tr>
<td></td>
<td>2006</td>
<td>387.00 ± 74.22</td>
<td>276.00 ± 72.76</td>
<td>111.00 ± 88.6</td>
<td>0.016</td>
<td>1.41 ± 1.13</td>
<td>Large</td>
</tr>
<tr>
<td></td>
<td>2007</td>
<td>362.14 ± 45.56</td>
<td>253.23 ± 73.68</td>
<td>108.91 ± 67.23</td>
<td>0.009</td>
<td>1.71 ± 1.06</td>
<td>Large</td>
</tr>
<tr>
<td></td>
<td>2008</td>
<td>423.86 ± 93.94</td>
<td>246.60 ± 25.14</td>
<td>177.26 ± 88.07</td>
<td>0.002</td>
<td>2.32 ± 1.13</td>
<td>Very Large</td>
</tr>
</tbody>
</table>

KPI, Key performance indicator; AAT, Average Air Time; ADR, Average Degree of Rotation; s, seconds; °, degrees; (p), P-value. Briefly the criteria for interpreting effect size were: <0.2 trivial, 0.2-0.6 small, 0.6-1.2 moderate, 1.2-2.0 large, > 2.0 very large, > 4.0 infinite (Hopkins, 2004). Confidence limits were set at 95 per cent, statistical significance set at P <0.05.

As this study assessed the Burton Open Australian half-Pipe Championships over a three year period, the longitudinal changes in half-pipe snowboard specific KPI performance could additionally be addressed (Figure 15). Although not all mean differences are statistically significant, male athletes show a longitudinal trend of increasing KPI performances from year to year. There is a statistically significance of both AAT and ADR performance by male finalists between the year 2006 and 2008. The performances of female athletes on the other hand show no such trend and there are no statistical significant differences associated with KPI performances between any year of the competition. Whilst men’s half-pipe snowboarding performance levels are well established and show increasingly levels of performance, women’s half-pipe snowboarding performance are evolving, consistent with an emergent competitor base.
Figure 15. Longitudinal changes in KPI performance over three years of the Burton Open Australian Half-Pipe Championships for male athletes (finalists, n = 12 performances in each year) and female athletes (finalists, n = 6 performances in each year). Data presented as mean ± SD, statistical significance set at P <0.05, * Denotes statistical significance in group performance of KPI's between 2006 and 2008. Men’s Competitions (top), Women’s Competitions (bottom).

3.1.2 Fédération Internationale de Ski (FIS) World Cup Competitions

As was the case with previous research focussed on a three year analysis of the Burton Open Australian Half-Pipe Championships, this study established that during all three FIS World Cup competitions, average air time and average degree of rotation were the strongest individual key performance indicators when correlated to subjectively judged scores (Table 8). Individually, average air time alone explains 52 - 64% of the shared variance in subjectively judged scores and average degree of rotation alone explains 17 – 41% of the shared variance in subjectively judged scores in the men’s competitions. Similarly, average air time alone explains 60 – 90% of the shared variance in subjectively judged scores and average degree of rotation alone explains 27 - 61% of the shared variance in subjectively judged scores in the women’s competitions. Interestingly, in all instances, AAT is a stronger KPI than ADR, always possessing the
capacity to explain a larger proportion of the shared variance in competition scores. The fact that AAT performance is a stronger KPI in all FIS WC half-pipe snowboarding competitions is objective information that may prove practically relevant to elite-level athletes striving to increase competitive success in the FIS WC half-pipe snowboarding competition circuit.

**Table 8.** Linear regression analysis of strongest individual key performance indicators when correlated to subjectively judged scores during three consecutive FIS World Cup half-pipe snowboard competitions (2006).

<table>
<thead>
<tr>
<th>Competition</th>
<th>Date</th>
<th>KPI</th>
<th>r</th>
<th>CL</th>
<th>p</th>
<th>r²</th>
<th>SEE</th>
<th>n</th>
<th>Predicted Score Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K1</td>
<td>09/01/06</td>
<td>AAT(s)</td>
<td>0.75</td>
<td>0.13</td>
<td>&lt;0.001</td>
<td>0.57</td>
<td>4.32</td>
<td>46</td>
<td>PS = 40.90AAT – 26.57</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>ADR(°)</td>
<td>0.64</td>
<td>0.18</td>
<td>&lt;0.001</td>
<td>0.41</td>
<td>5.02</td>
<td>46</td>
<td>PS = 0.046ADR – 8.77</td>
</tr>
<tr>
<td>L1</td>
<td>18/01/06</td>
<td>AAT(s)</td>
<td>0.72</td>
<td>0.19</td>
<td>&lt;0.001</td>
<td>0.52</td>
<td>4.42</td>
<td>29</td>
<td>PS = 37.91AAT – 21.86</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>ADR(°)</td>
<td>0.56</td>
<td>0.26</td>
<td>0.002</td>
<td>0.31</td>
<td>5.26</td>
<td>29</td>
<td>PS = 0.040ADR – 12.87</td>
</tr>
<tr>
<td>L2</td>
<td>19/01/06</td>
<td>AAT(s)</td>
<td>0.80</td>
<td>0.16</td>
<td>&lt;0.001</td>
<td>0.64</td>
<td>4.19</td>
<td>25</td>
<td>PS = 42.82AAT – 30.61</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>ADR(°)</td>
<td>0.42</td>
<td>0.33</td>
<td>0.038</td>
<td>0.17</td>
<td>6.36</td>
<td>25</td>
<td>PS = 0.030ADR – 18.27</td>
</tr>
<tr>
<td>Women</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K1</td>
<td>09/01/06</td>
<td>AAT(s)</td>
<td>0.77</td>
<td>0.18</td>
<td>&lt;0.001</td>
<td>0.60</td>
<td>4.69</td>
<td>24</td>
<td>PS = 35.47AAT – 9.26</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>ADR(°)</td>
<td>0.66</td>
<td>0.25</td>
<td>&lt;0.001</td>
<td>0.43</td>
<td>5.55</td>
<td>24</td>
<td>PS = 0.088ADR – 2.78</td>
</tr>
<tr>
<td>L1</td>
<td>18/01/06</td>
<td>AAT(s)</td>
<td>0.85</td>
<td>0.20</td>
<td>&lt;0.001</td>
<td>0.72</td>
<td>4.56</td>
<td>13</td>
<td>PS = 61.31AAT – 37.03</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>ADR(°)</td>
<td>0.52</td>
<td>0.44</td>
<td>0.070</td>
<td>0.27</td>
<td>7.33</td>
<td>13</td>
<td>PS = 0.081ADR – 6.61</td>
</tr>
<tr>
<td>L2</td>
<td>19/01/06</td>
<td>AAT(s)</td>
<td>0.95</td>
<td>0.07</td>
<td>&lt;0.001</td>
<td>0.90</td>
<td>3.01</td>
<td>13</td>
<td>PS = 72.68AAT – 45.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>ADR(°)</td>
<td>0.78</td>
<td>0.26</td>
<td>0.002</td>
<td>0.61</td>
<td>5.98</td>
<td>13</td>
<td>PS = 0.113ADR – 7.68</td>
</tr>
</tbody>
</table>

KPI, Key performance indicator; AAT, Average Air Time; ADR, Average Degree of Rotation; s, seconds; °, degrees. All correlations are presented as correlation coefficient (r) ± 95 per cent confidence limits (CL), P-value (p), coefficient of determination (r²), standard error of the estimate (SEE), sample size, number of runs analysed (n); predicted score regression equation (PS). Confidence limits were set at 95 per cent, statistical significance set at P <0.05.

When the two strongest objective, individual key performance indicators AAT and ADR are combined using a multiple regression (enter method) they explain approximately 66%, 73%, and 75% of the shared variance in subjectively judged scores in the men’s FIS WC half-pipe snowboarding competitions and approximately 74%, 75% and 94% of the shared variance in subjectively judged scores in the women’s FIS WC half-pipe snowboarding competitions during the events of K1, L1, L2 respectively (Table 9). Again, the fact that one hundred percent of the shared variance in subjectively judged scores could not be explained using an objective approach should
not be considered a weakness of this approach but a strength as the subjective components of style and execution should never be removed from the sport.

**Table 9.** Multiple linear regression analysis (enter method) of the combination of strongest individual key performance indicators AAT and ADR and their relationship to subjectively judged scores during three consecutive FIS World Cup half-pipe snowboard competitions (2006). Strongest individual key performance indicators determined by strength of individual correlation to scores during each competition (Table 1).

<table>
<thead>
<tr>
<th>Competition</th>
<th>KPI</th>
<th>$r$</th>
<th>CL</th>
<th>$p$</th>
<th>$r^2$</th>
<th>SEE</th>
<th>n</th>
<th>Predicted Score Regression Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K1</td>
<td>AAT/ADR</td>
<td>0.81</td>
<td>0.11</td>
<td>&lt;0.001</td>
<td>0.66</td>
<td>3.88</td>
<td>46</td>
<td>$PS = 31.21AAT + 0.025ADR - 25.86$</td>
</tr>
<tr>
<td>L1</td>
<td>AAT/ADR</td>
<td>0.85</td>
<td>0.11</td>
<td>&lt;0.001</td>
<td>0.73</td>
<td>3.38</td>
<td>29</td>
<td>$PS = 34.27AAT + 0.033ADR - 32.89$</td>
</tr>
<tr>
<td>L2</td>
<td>AAT/ADR</td>
<td>0.87</td>
<td>0.11</td>
<td>&lt;0.001</td>
<td>0.75</td>
<td>3.59</td>
<td>25</td>
<td>$PS = 40.79AAT + 0.024ADR - 39.60$</td>
</tr>
<tr>
<td>Women</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K1</td>
<td>AAT/ADR</td>
<td>0.86</td>
<td>0.12</td>
<td>&lt;0.001</td>
<td>0.74</td>
<td>3.88</td>
<td>24</td>
<td>$PS = 27.72AAT + 0.055ADR - 18.45$</td>
</tr>
<tr>
<td>L1</td>
<td>AAT/ADR</td>
<td>0.87</td>
<td>0.17</td>
<td>&lt;0.001</td>
<td>0.75</td>
<td>4.50</td>
<td>13</td>
<td>$PS = 55.29AAT + 0.031ADR - 39.21$</td>
</tr>
<tr>
<td>L2</td>
<td>AAT/ADR</td>
<td>0.97</td>
<td>0.05</td>
<td>&lt;0.001</td>
<td>0.94</td>
<td>2.55</td>
<td>13</td>
<td>$PS = 59.63AAT + 0.037ADR - 43.18$</td>
</tr>
</tbody>
</table>

KPI, Key performance indicator; AAT, Average Air Time; ADR, Average Degree of Rotation; AAT/ADR, Combination of AAT and ADR by multiple linear regression (enter method); K1, Kreischberg Austria, L1, Leysin Switzerland; L2, Leysin Switzerland different date.. All correlations are presented as correlation coefficient ($r$) ± 95 per cent confidence limits (CL), P-value ($p$), coefficient of determination ($r^2$), standard error of the estimate (SEE), sample size, number of runs analysed (n); predicted score regression equation ($PE$). Confidence limits were set at 95 per cent, statistical significance set at $P <0.05$.

A key aspect of this study was the magnitude of difference in performance between Finalists and Qualifiers in FIS WC half-pipe snowboard competitions. The differing levels of performance in terms of average air time and average degree of rotation between those two groups of athletes are shown in Table 10. Finalists routinely perform better in terms of average air time and average degree of rotation than Qualifiers. Although not all mean differences are statistically significant, the differences between the means of average air time and average degree of rotation between these two groups routinely show moderate to very large effects. The relative importance of average air time and average degree of rotation performance in elite-level half-pipe snowboarding competition has been established by this study to be similar in both the Burton Open Australian Half-Pipe Championships over three years and also during three consecutive FIS WC Half-Pipe Snowboarding Competitions, events with vastly different ruling bodies and participant numbers. The large amount of shared variance explained by the same objective measures in all these events has strong application for coaches, athletes and judges in terms of accurately assessing performance and training for competition.
Table 10. Absolute and magnitude-based differences between performance of AAT and ADR by Finalists and Qualifiers during three consecutive FIS World Cup half-pipe snowboard competitions (2006). Data presented as AAT (s) or ADR (°), (Mean ± SD). Magnitude of difference (reported as mean difference ± 95% CL, significance, effect size ± 95% CL, and rating). Positive effect size value indicates athletes achieving top three final rankings perform better in terms of AAT or ADR than those achieving final rankings outside the top three.

<table>
<thead>
<tr>
<th>KPI, Comp</th>
<th>Finalists</th>
<th>Qualifiers</th>
<th>Mean Diff</th>
<th>p</th>
<th>Effect Size</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>K1</td>
<td>1.54 ± 0.08</td>
<td>1.44 ± 0.12</td>
<td>0.10 ± 0.06</td>
<td>0.008</td>
<td>1.01 ± 0.61</td>
</tr>
<tr>
<td>AAT(s)</td>
<td>L1</td>
<td>1.52 ± 0.10</td>
<td>1.37 ± 0.09</td>
<td>0.15 ± 0.10</td>
<td>&lt;0.001</td>
<td>1.54 ± 0.77</td>
</tr>
<tr>
<td></td>
<td>L2</td>
<td>1.58 ± 0.12</td>
<td>1.42 ± 0.07</td>
<td>0.16 ± 0.08</td>
<td>&lt;0.001</td>
<td>1.56 ± 0.82</td>
</tr>
<tr>
<td></td>
<td>K1</td>
<td>606.50 ± 73.24</td>
<td>518.12 ± 86.30</td>
<td>88.38 ± 53.52</td>
<td>0.003</td>
<td>1.08 ± 0.66</td>
</tr>
<tr>
<td>ADR(°)</td>
<td>L1</td>
<td>549.50 ± 77.91</td>
<td>454.03 ± 72.87</td>
<td>95.47 ± 59.32</td>
<td>0.002</td>
<td>1.23 ± 0.76</td>
</tr>
<tr>
<td></td>
<td>L2</td>
<td>541.00 ± 90.92</td>
<td>468.73 ± 86.83</td>
<td>72.27 ± 73.87</td>
<td>0.054</td>
<td>0.79 ± 0.80</td>
</tr>
<tr>
<td>Women</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>K1</td>
<td>1.25 ± 0.08</td>
<td>1.13 ± 0.17</td>
<td>0.12 ± 0.11</td>
<td>0.091</td>
<td>0.92 ± 0.80</td>
</tr>
<tr>
<td>AAT(s)</td>
<td>L1</td>
<td>1.18 ± 0.04</td>
<td>0.99 ± 0.07</td>
<td>0.19 ± 0.07</td>
<td>&lt;0.001</td>
<td>2.99 ± 1.13</td>
</tr>
<tr>
<td></td>
<td>L2</td>
<td>1.11 ± 0.10</td>
<td>0.92 ± 0.11</td>
<td>0.19 ± 0.13</td>
<td>0.011</td>
<td>1.66 ± 1.19</td>
</tr>
<tr>
<td></td>
<td>K1</td>
<td>360.00 ± 39.98</td>
<td>320.90 ± 55.37</td>
<td>39.10 ± 46.00</td>
<td>0.088</td>
<td>0.78 ± 0.92</td>
</tr>
<tr>
<td>ADR(°)</td>
<td>L1</td>
<td>307.14 ± 56.90</td>
<td>254.76 ± 36.71</td>
<td>52.38 ± 62.40</td>
<td>0.070</td>
<td>1.00 ± 1.19</td>
</tr>
<tr>
<td></td>
<td>L2</td>
<td>378.00 ± 70.23</td>
<td>264.70 ± 41.00</td>
<td>113.30 ± 88.92</td>
<td>0.003</td>
<td>1.74 ± 1.37</td>
</tr>
</tbody>
</table>

KPI, Key performance indicator; AAT, Average Air Time; ADR, Average Degree of Rotation; s, seconds; °, degrees; (p), P-value. Briefly the criteria for interpreting effect size were: <0.2 trivial, 0.2-0.6 small, 0.6-1.2 moderate, 1.2-2.0 large, > 2.0 very large, > 4.0 infinite (Hopkins, 2004). Confidence limits were set at 95 per cent, statistical significance set at P <0.05.

An additional aspect of this study was the within-subject variation in AAT and ADR performances between two consecutive FIS World Cup Half-Pipe Snowboarding Competitions conducted in Leysin Switzerland on the 18th and 19th January 2006 (Table 11). For the most part there is a small degree of variation in KPI performances from competition to competition. The coefficient of variation associated with AAT and ADR is 4.42% and 5.14% for male athletes and 4.03% and 15.48% for female athletes respectively. The large coefficient of variation associated with female ADR performance from competition to competition is theorised to be resultant of the emergent competitor base and evolving levels of performance in women’s snowboarding at the time. The Smallest Worthwhile Change (half the Coefficient of Variation) is the average change in performance of AAT and ADR required to increase or decrease competition rankings. For male half-pipe snowboarders, a change in AAT by 0.03s and a change in ADR by 12.92° (on average) has the potential to change their
final competition ranking. It is important to note that these values are associated with the two strongest key performance indicators AAT and ADR and so when applying these values in terms of a complete competition run (which on average consists of approximately 6 aerial acrobatic manoeuvres) a change in total air time (TAT) and total degree of rotation (TDR) by approximately 0.18s and 77.52° respectively can change a competitors final competition ranking. In terms of air time, this is straightforward and in terms of degree of rotation (of which the smallest sport specific increase or decrease is 180 degrees), an extra 180 degree rotation achieved somewhere within a competition run has the potential to enhance competition performance. For female half-pipe snowboarders, an increase of 0.02s in AAT and 23.89° in ADR has the potential to either increase or decrease final competition rankings. Similarly, for female half-pipe snowboarders, an increase in TAT of approximately 0.12s and the completion of an extra 180 degree rotation somewhere within a run has the potential to increase their final competition ranking.

Table 11. Within-Subject Variation in AAT and ADR performances between two consecutive FIS World Cup Half-Pipe Snowboarding Competitions (Leysin Switzerland, 18th and 19th January 2006). Smallest Worthwhile Change (SMC) is the average change in performance of AAT and ADR required to increase or decrease competition rankings.

<table>
<thead>
<tr>
<th>KPI</th>
<th>Mean Difference ± SD</th>
<th>Range (Absolute)</th>
<th>Mean CV (%)</th>
<th>SMC (%)</th>
<th>SMC (Absolute)</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AAT(s)</td>
<td>-0.06 ± 0.10</td>
<td>-0.24 - 0.09</td>
<td>4.24</td>
<td>2.12</td>
<td>0.03</td>
<td>21</td>
</tr>
<tr>
<td>ADR(°)</td>
<td>-0.24 ± 51.29</td>
<td>-90.00 – 108.00</td>
<td>5.14</td>
<td>2.57</td>
<td>12.92</td>
<td>21</td>
</tr>
<tr>
<td>Women</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AAT(s)</td>
<td>0.03 ± 0.07</td>
<td>-0.05 – 0.13</td>
<td>4.03</td>
<td>2.02</td>
<td>0.02</td>
<td>7</td>
</tr>
<tr>
<td>ADR(°)</td>
<td>-43.56 ± 90.26</td>
<td>-198.00 – 60.00</td>
<td>15.48</td>
<td>7.74</td>
<td>23.89</td>
<td>7</td>
</tr>
</tbody>
</table>

KPI, Key performance indicator; AAT, Average Air Time; ADR, Average Degree of Rotation; s, seconds; °, degrees; CV, Coefficient of Variation; SMC, Smallest Worthwhile Change.

3.1.3 Australian Institute of Sport (AIS) Micro-Tech Pipe Challenge

During the AIS Micro-Tech Pipe Challenge the key performance indicators associated with this event, average air time and average degree of rotation were the strongest individual key performance indicators when correlated to subjectively judged scores (Table 12). Individually, average air time alone explained 23% of the shared variance in subjectively judged scores and average degree of rotation alone explained 76% of the shared variance in subjectively judged scores during the AIS Micro-Tech Pipe Challenge 2007.
Table 12. Linear regression analysis of strongest individual key performance indicators when correlated to subjectively judged scores during Burton Open Australian Half-Pipe Challenge (2006 - 2008).

<table>
<thead>
<tr>
<th>Year</th>
<th>KPI</th>
<th>r</th>
<th>CL</th>
<th>p</th>
<th>r²</th>
<th>SEE</th>
<th>n</th>
<th>Predicted Score Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>AAT(s)</td>
<td>0.48</td>
<td>0.38</td>
<td>&lt;0.040</td>
<td>0.23</td>
<td>1.67</td>
<td>18</td>
<td>$PS = 7.50AAT - 3.12$</td>
</tr>
<tr>
<td></td>
<td>ADR(°)</td>
<td>0.87</td>
<td>0.14</td>
<td>&lt;0.001</td>
<td>0.76</td>
<td>0.94</td>
<td>18</td>
<td>$PS = 0.011ADR + 2.09$</td>
</tr>
</tbody>
</table>

KPI, Key performance indicator; AAT, Average Air Time; ADR, Average Degree of Rotation; s, seconds; °, degrees. All correlations are presented as correlation coefficient ($r$) ± 95 per cent confidence limits (CL), P-value ($p$), coefficient of determination ($r^2$), standard error of the estimate (SEE), sample size, number of runs analysed ($n$); predicted score regression equation ($PS$). Confidence limits were set at 95 per cent, statistical significance set at $P < 0.05$.

When the two strongest objective, individual key performance indicators AAT and ADR are combined using a multiple regression (enter method) they explain approximately 80% of the shared variance in subjectively judged scores during the AIS Micro-Tech Pipe Challenge 2007 (Table 13).

Table 13. Multiple linear regression analysis (enter method) of the combination of strongest individual key performance indicators AAT and ADR and their relationship to subjectively judged scores during the Burton Open Australian Half-pipe Championships (2006 – 2008). Strongest individual key performance indicators determined by strength of individual correlation to scores during each competition (Table 1).

<table>
<thead>
<tr>
<th>Year</th>
<th>KPI</th>
<th>r</th>
<th>CL</th>
<th>p</th>
<th>r²</th>
<th>SEE</th>
<th>n</th>
<th>Predicted Score Regression Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>AAT/ADR</td>
<td>0.89</td>
<td>0.11</td>
<td>&lt;0.001</td>
<td>0.80</td>
<td>0.88</td>
<td>18</td>
<td>$PS = 3.421AAT + 0.011ADR - 1.79$</td>
</tr>
</tbody>
</table>

KPI, Key performance indicator; AAT, Average Air Time; ADR, Average Degree of Rotation; AAT/ADR, Combination of AAT and ADR by multiple linear regression (enter method). All correlations are presented as correlation coefficient ($r$) ± 95 per cent confidence limits (CL), P-value ($p$), coefficient of determination ($r^2$), standard error of the estimate (SEE), sample size, number of runs analysed ($n$); predicted score regression equation ($PS$). Confidence limits were set at 95 per cent, statistical significance set at $P < 0.05$.

A key aspect of this study was the magnitude of difference in performance between athletes achieving top three final rankings and those athletes achieving final rankings outside the top three finish places. The differing levels of performance in terms of average air time and average degree of rotation between those groups are shown in Table 14. Athletes achieving top three final rankings routinely perform better in terms of average air time and average degree of rotation than those athletes who achieve final rankings outside the top three finish places. Although not all mean differences are statistically significant, the magnitude of difference between the means of average air time and average degree of rotation between these two groups is moderate to very large respectively. The relative importance of average air time and average degree of rotation
performance in all half-pipe snowboarding competitions assessed by this study is believed to provide a basis for developing and implementing individual athlete strategy, reliable assessment of performance progression in training, team selection criteria and additionally, enhanced competition judging protocols for all levels of performance.

Table 14. Absolute and magnitude-based differences between performance of AAT and ADR by athletes who achieve top three final rankings and those that do not. Data presented as AAT (s) or ADR (°), (Mean ± SD), Magnitude of difference (reported as mean difference ± 95% CL, significance, effect size ± 95% CL, and rating). Positive effect size value indicates athletes achieving top three final rankings perform better in terms of AAT or ADR than those achieving final rankings outside the top three.

<table>
<thead>
<tr>
<th>KPI</th>
<th>Year</th>
<th>Top 3</th>
<th>Outside Top 3</th>
<th>Mean Diff</th>
<th>p</th>
<th>Effect Size</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAT(s)</td>
<td>2007</td>
<td>1.32 ± 0.07</td>
<td>1.20 ± 0.13</td>
<td>0.12 ± 0.13</td>
<td>0.147</td>
<td>1.07 ± 1.21</td>
<td>Moderate</td>
</tr>
<tr>
<td>ADR(°)</td>
<td>2007</td>
<td>544.00 ± 90.86</td>
<td>280.14 ± 99.44</td>
<td>263.86 ± 190.31</td>
<td>0.001</td>
<td>2.49 ± 1.80</td>
<td>Very Large</td>
</tr>
</tbody>
</table>

KPI, Key performance indicator; AAT, Average Air Time; ADR, Average Degree of Rotation; s, seconds; °, degrees; (p), P-value. Briefly the criteria for interpreting effect size were: ≤0.2 trivial, 0.2-0.6 small, 0.6-1.2 moderate, 1.2-2.0 large, > 2.0 very large, > 4.0 infinite (Hopkins, 2004). Confidence limits were set at 95 per cent, statistical significance set at P < 0.05.

3.1.4 2006 Winter Olympic Games

As the data set for the 2006 Winter Olympic Games comprised only KPI performance information in the finals and not the whole competition and associated qualifying round, we assessed this competition solely as the criterion standard for half-pipe snowboarding performance in 2006. In terms of the strongest KPI’s associated with competition performance (as established during the Burton Open Australian Half-Pipe Championships, three consecutive FIS World Cup Half-Pipe Snowboarding competitions and the AIS Micro-Tech Pipe Challenge), we established the current ‘gold standard’ (for the year 2006) associated with half-pipe snowboarding performance occurs when a male athlete achieves an AAT of 1.70 ± 0.07s and an ADR of 733.64 ± 40.52 and when a female athlete achieves an AAT of 1.40 ± 0.12s and an ADR of 444.00 ± 64.49° (Table 15.). Half-pipe snowboarding performances that achieve these levels are sufficient to make the finals in Olympic competition (in 2006). These performance levels have no doubt evolved since that time and objective measurement of the 2010 Winter Olympic Games Half-Pipe Snowboarding Competition conducted in the same manner as established during this study can generate the current ‘gold standard’ in terms of half-pipe snowboarding performance.
Table 15. Mean KPI performances associated with Finalists in the 2006 Winter Olympic Games half-pipe snowboard competition. Data presented as mean ± SD.

<table>
<thead>
<tr>
<th></th>
<th>TAT</th>
<th>AAT</th>
<th>HIAT</th>
<th>TDR</th>
<th>ADR</th>
<th>HIDR</th>
<th>HCDR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men</td>
<td>9.27 ± 0.25</td>
<td>1.70 ± 0.07</td>
<td>1.90 ± 0.09</td>
<td>4009.09 ± 509.7</td>
<td>733.64 ± 40.52</td>
<td>1080.00 ± 0.00</td>
<td>3780.00 ± 673.50</td>
</tr>
<tr>
<td>Women</td>
<td>8.07 ± 0.62</td>
<td>1.40 ± 0.12</td>
<td>1.60 ± 0.15</td>
<td>2574.00 ± 398.4</td>
<td>444.00 ± 64.49</td>
<td>792.00 ± 92.52</td>
<td>1440.00 ± 786.89</td>
</tr>
</tbody>
</table>

KPI, Key performance indicator; TAT, Total Air Time; AAT, Average Air Time; HIAT, Highest Individual Air Time; TDR, Total Degree of Rotation; ADR, Average Degree of Rotation; HIDR, Highest Individual Degree of Rotation; HCDR, Highest Cumulative Degree of Rotation. Means derived from Finalist’s best runs (men, n = 11; women, n = 10) during 2006 Winter Olympic Games.

3.2 Sports Technology

Accurate and reliable feedback can improve athletic performance and provides a basis for developing and implementing individual athlete strategy, dependable assessment of performance progression, and team selection criteria. It must however be provided in a timely manner to be valuable in both a training and competition performance assessment environment. Video based analysis (such as that used in this study) is labour intensive and associated with a large time delay in information feedback. This study therefore customised wearable sensor technology to develop an automated performance feedback system suitable for calculation of air time and degree of rotation in routine training and competition environments. Micro-technology such as tri-axial accelerometers and tri-axial rate gyroscopes generate data that when used in combination with signal processing techniques can automatically quantify accurate and reliable objective information specific to the sport of half-pipe snowboarding. The data obtained from tri-axial accelerometer sensors can be processed automatically with mathematical algorithms to quantify the air time associated with aerial acrobatics performed during half-pipe snowboarding. When this air time information is used in combination with the processed data obtained from tri-axial rate gyroscopes, it is possible to quantify degree of rotation and thereby classify the degree of complexity associated with the same aerial acrobatics. The capacity of technology to generate this practically relevant information without hindrance to athletic performance can be applied to all half-pipe snowboarding environments and has the potential to enhance both training performance assessment and competition judging reliability.
3.2.1 50Hz Video Based Quantification

This study investigated the use of both 50Hz and 200Hz video footage to quantify the air times associated with half-pipe snowboarding performance in order to serve as a criterion reference for air time quantification provided by customised wearable technology. For this specific application, there is no statistically significant difference between the air times quantified by using a 50Hz panning digital video footage and those quantified by using 200Hz digital video footage. Table 16 shows that half-pipe snowboarding air times quantified by using 50Hz video footage show a perfect correlation (Hopkins, 2004) with the criterion reference standard ($r = 0.99 \pm 0.001$, $p <0.001$, $r^2 = 0.98$, $SEE = 0.01$, mean bias $= 0.004 \pm 0.004$, $n = 18$). Unlike 50Hz video cameras, high speed video cameras can only capture one aerial acrobatic manoeuvre during each half-pipe snowboard run as a result of the inability to zoom in or out (manual zoom). High speed camera use is also labour intensive, requires substantial wiring in order to store data, and is very difficult to set up in harsh environmental conditions. For these reasons and the fact that this study has established there is no statistically significant differences between air time quantification (for our application) using either method, 50Hz video footage was used to assess the accuracy and reliability of inertial sensor based practical methods of air time quantification and for this application, can be considered the criterion reference standard.

Table 16. Validation of air time quantification using 50Hz panning video footage against a criterion reference (200Hz High Speed video Footage).

<table>
<thead>
<tr>
<th>$r$</th>
<th>CL</th>
<th>$p$</th>
<th>$r^2$</th>
<th>$SEE$</th>
<th>$n$</th>
<th>PAT</th>
<th>Mean Bias</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.99</td>
<td>0.001</td>
<td>&lt;0.001</td>
<td>0.98</td>
<td>0.01</td>
<td>18</td>
<td>$PE=1.028AT-0.043$</td>
<td>0.004 ± 0.005</td>
</tr>
</tbody>
</table>

All correlations are presented as correlation coefficient ($r$) ± 95 per cent confidence limits (CL), P-value ($p$), coefficient of determination ($r^2$), standard error of the estimate ($SEE$), sample size, number of runs analysed ($n$); predicted air time regression equation ($PAT$). Confidence limits were set at 95 per cent, statistical significance set at $P <0.05$.

3.2.2 Wearable Inertial Sensors

This study demonstrates that half-pipe snowboarding runs performed by instrumented athletes generate a distinct repeatable tri-axial accelerometer pattern that displays elevated accelerations throughout the take off and landings and a period of minimal force readings throughout the air time phase associated with aerial acrobatic manoeuvres (Figure 16). Both half-pipe snowboarding run detection and air-time calculation was possible because of the rapid increases and decreases in acceleration in
both the up/down and forward/back accelerometer axes. These rapid changes in acceleration occur when athletes progresses up, out of and eventually re-enter the vertical half-pipe transitions during the performance of aerial acrobatic manoeuvres. The properties of accelerometers are such that upon coming into contact with the earth’s surface following a period of air-time, there is a brief period of augmented activity and high force readings from which aerial acrobatic landings can be detected. This is a novel finding and provided the basis for the development of automated methods of air time quantification using tri-axial accelerometer data obtained during half-pipe snowboarding.

**Figure 16.** A raw, unfiltered tri-axial accelerometer data output trace associated with a half-pipe snowboarding run. Note the distinct, repeated pattern generated by the performance of a number of consecutive aerial acrobatic manoeuvres during a half-pipe snowboarding run. A1, Accelerometer 1 (forward/backwards); A3, Accelerometer 3 (upwards/downwards).

Although there were numerous algorithmic methods trialled throughout this study, this thesis provides validation results for the two most promising techniques. This study allowed a criterion-referenced validation of the air-times (Method One, mean 1.28s ± 0.15s, n = 102; Method Two, mean 1.28s ± SD 0.13s, n = 92) quantified by customised wearable technology and the signal processing methods presented in this study. (Results are presented as value ± 95% confidence limits). 0.15s was deemed an acceptable error for automatic air time quantification based on the fact that it 0.15s of air-time (spent totally in freefall) calculates to a vertical distance travelled of approximately 11.03cm (derived from \( x = \frac{1}{2} at^2 \)). This is not a significant difference in air-time during elite half-pipe snowboarding particularly when you consider that it
A 5.51 cm increase in the jump height (equal to the error in the image based height measurement system developed by EIM-Solutions (Table 1).

### 3.3 Air-Time Algorithm Validation

Automatic quantification of air time associated with elite half-pipe snowboarding may prove beneficial in assisting elite-level coaching and competition judging protocols. This study demonstrates that air time can be calculated using tri-axial accelerometer outputs and signal processing techniques.

#### 3.3.1 Method One

There was an almost perfect correlation \( (r = 0.92 \pm 0.03, p \text{ value} < 0.0001, r^2 = 0.85, \text{SEE} = 0.06, n = 102, PE = 1.006AT + 0.002) \) between the criterion (video based analysis, y-axis) and practical (accelerometer based signal processing technique, x-axis) methods (Table 17, Figure 17). The mean bias between the criterion and practical measures of air-time was \(-0.01 \pm 0.01\) s (Table 17) and the 95% confidence limits related to the mean bias were \(-0.02\) s and \(-0.00\) s (Figure 18). There was uniformity in the residuals shown by a mean bias of \(-0.01\) s \(\pm 0.00\) s at the low end of the air-time scale (1.00 s of air-time) and a mean bias of \(-0.01\) s \(\pm 0.03\) s at the high end of the air-time scale (1.60 s of air-time). Approximately 97\% (97.10\%) of the practical measures lie within \(\pm 0.15\) s of the criterion measure (0.15 s was deemed an acceptable error for automatic air time quantification). The signal processing technique used for Method One however generated 2.00 False Positives (detecting and quantifying an air time for a non-existent aerial acrobatic manoeuvre) and 25.00 False Negatives (failing to detect and quantify an air time for aerial acrobatic manoeuvres performed in the study).

<table>
<thead>
<tr>
<th>Method</th>
<th>( r )</th>
<th>( CL )</th>
<th>( p )</th>
<th>( r^2 )</th>
<th>( \text{SEE} )</th>
<th>( n )</th>
<th>( \text{PAT} )</th>
<th>Mean Bias</th>
<th>False Positives</th>
<th>False Negatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.92</td>
<td>0.03</td>
<td>&lt;0.001</td>
<td>0.85</td>
<td>0.06</td>
<td>102</td>
<td>( PE = 1.006AT + 0.002 )</td>
<td>-0.01 ± 0.01</td>
<td>2</td>
<td>25</td>
</tr>
<tr>
<td>2</td>
<td>0.78</td>
<td>0.08</td>
<td>&lt;0.001</td>
<td>0.61</td>
<td>0.08</td>
<td>92</td>
<td>( PE = 0.748AT + 0.302 )</td>
<td>0.03 ± 0.02</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

All correlations are presented as correlation coefficient \( (r) \) ± 95 per cent confidence limits \( (CL) \), P-value \( (p) \), coefficient of determination \( (r^2) \), standard error of the estimate \( (\text{SEE}) \), sample size, number of runs analysed \( (n) \); predicted air time regression equation \( (\text{PAT}) \). Confidence limits were set at 95 per cent, statistical significance set at \( P < 0.05 \).
Figure 17. Method One Validation. Correlation between the criterion method (video based quantification) and the practical method (automated processing of tri-axial accelerometer data) for air-time calculation ($r = 0.92 \pm 0.03$, p value < 0.0001, SEE = 0.06, n = 102, PE = $1.006AT + 0.002$). Note: False positive and false negative air time detection and quantification data points are not shown on graph and do not comprise data points in linear regression analysis. (---), 95%CL.

The mean bias (-0.01 ± 0.01s) shows that Method One on average, measures air-time slightly lower than the criterion method (Table 17, Figure 18). There was a degree of non-uniformity in the bias between the criterion and practical methods however the bias inherent in the practical method at low and high ends of the air-time scale (for example 1.00s and 1.6s of air-time) were no larger than the mean (bias = 0.01 ± 0.02s and -0.01s ± 0.03s respectively). At low air-times it is possible for the practical method to measure higher and for high air-times it is possible for the practical method to measure lower than the criterion method, albeit with no significant relationship in the non-uniformity of this bias. It seems the non-uniformity was generated by outliers rather than being a systematic effect of increasing air-time. As such the utilisation of a calibration equation is of no use in correcting the slight non-uniformity within this data sample.

Approximately 97% (97.10%) of the practical measures lie within ± 0.15s of the criterion measure. Improved accuracy will always be a focus however the inability of Method One to quantify air times for aerial acrobatic manoeuvres without the generation of false positives and false negatives severely limits its ability to be successfully integrated into half-pipe snowboarding training environments.
3.3.2 Method Two

There was a very large correlation \((r = 0.78 \pm 0.08; \ p \text{ value} < 0.0001; \ r^2 = 0.61, \ SEE = 0.08, \ n = 92, \ PE = 0.748\text{AT}+0.302)\) between the criterion (video based analysis, y-axis) and practical (accelerometer based signal processing technique, x-axis) methods (Table 17, Figure 19). The mean bias between the criterion and practical measures of air-time was \(-0.03 \pm 0.02\text{s}\) and the 95% confidence limits related to the mean bias were \(-0.01\text{s}\) and \(-0.05\text{s}\) (Figure 20). There was however, indication of a small degree of non-uniformity in the residuals (heteroscedasticity) shown for example by the bias of \(0.05\text{s} \pm 0.04\text{s}\) at the low end of the air-time scale (1.00s of air-time) and the bias of \(-0.10\text{s} \pm 0.04\text{s}\) at the high end of the air-time scale (1.60s of air-time). Approximately 95% (94.57%) of the practical measures lie within \(\pm 0.15\text{s}\) of the criterion measure. Method Two however was able to detect 100 percent of the aerial acrobatic manoeuvres performed during this study and generated 0.00 False Positives and 0.00 False Negatives.
Figure 19. Method Two Validation. Correlation between the criterion method (video based quantification) and the practical method (automated processing of tri-axial accelerometer data) for air-time calculation ($r = 0.78 \pm 0.08$; $p$ value $< 0.0001$; SEE $= 0.08$, $n = 92$). Note: False positive and false negative air time detection and quantification data points are not shown on graph and do not comprise data points in linear regression analysis. Method Two produced zero false positives and zero false negatives. (- - -), 95% CL.

The mean bias ($0.03 \pm 0.02$s) shows that Method Two on average, measures air-time slightly higher than the criterion method (Figure 20). There was however a degree of non-uniformity in the bias between the criterion and practical methods. The bias inherent in the practical method at low and high ends of the air-time scale (for example 1.00s and 1.6s of air-time) were somewhat larger than the mean (bias $= 0.05 \pm 0.04$s and $-0.10s \pm 0.04$s respectively). At low air-times it is possible for the practical method to measure higher and for high air-times it is possible for the practical method to measure lower than the criterion method. There was however, no significant relationship in the non-uniformity of this bias. It seems the non-uniformity was generated by outliers rather than being a systematic effect of increasing air-time. As such the utilisation of a calibration equation is of no use in correcting the slight non-uniformity within this data sample. Approximately 95% (94.57%) of the practical measures lie within $\pm 0.15$s of the criterion measure. Although $\pm 0.15$s of error (11.7% error at the average air-time of 1.28s) was deemed to be acceptable for the purpose of this concept, further research will focus on reducing the mean bias associated with the practical method. Improved accuracy will always be a focus however, the capacity of the practical method to calculate air-time for 100 percent of aerial acrobatic manoeuvres where 94.7% of measures fell within $\pm 0.15$s of the criterion will allow successful integration of this concept into half-pipe snowboarding training environments.
The validity associated with quantification of air-time using the tri-axial accelerometer based practical methods was tested against the video based criterion method. Although Method One showed a larger, almost perfect correlation \((r = 0.92, \text{SEE} = 0.06, \text{mean bias} = -0.01s, n = 102)\) with the video based criterion method, Method Two was considered to be more reliable and a superior method. This was because Method Two was able to detect 100 percent of the aerial acrobatic manoeuvres performed throughout the study as opposed to the 79.10 percent detection generated by Method One. False positive and false negative air-time calculation would have an overwhelming detrimental effect on any automated feedback provided within elite-level coaching or competition judging environments. Subsequently, the capacity of the technique to reliably detect air-times with the absence of false positives of false negatives was considered to be an extremely important factor for the successful integration of this concept into elite-level half-pipe snowboard training and competition protocols.

### 3.4 Degree of Rotation Algorithm Validation

As established by this study, air-time is not the only objective performance variable that impacts on an athlete’s subjectively judged competition score. We have shown that degree of rotation associated with half-pipe snowboard manoeuvres also explains a large amount of the variance in subjectively judged competition scores. This study
therefore developed, validated and integrated a signal processing technique to classify the degree of rotation associated with half-pipe snowboarding aerial acrobatic manoeuvres. This study investigated the effectiveness of processing rate gyroscope data using numerical integration to classify half-pipe snowboarding aerial acrobatics into sport specific rotational groups. The signal processing of tri-axial rate gyroscope data was used in combination with previously described methods of air time quantification using signal processing techniques on tri-axial rate gyroscope data. The calculation of air-time associated with aerial acrobatics performed during half-pipe snowboarding provided the duration over which to assess angular velocity data generated by tri-axial rate gyroscopes. The terminology used by the ‘practice community’ to describe acrobatic rotation is based upon an approximation of angular displacement and the relationship between direction of travel at take-off and landing. Provided rotations are performed predominantly around a single axis, the signal processing method presented in this paper provides reliable classification of aerial acrobatics.

3.4.1 Method One

Figure 21 shows the signal processing technique output (Air Angle) associated with a number of different aerial acrobatic manoeuvres performed during a single half-pipe snowboarding run. Figure 22 presents Air Angle (mean ± maximum and minimum range) for aerial acrobatics and their relationship to one of four rotational groups routinely used by the ‘practice community’ (based upon an approximation of angular displacement). Average Air Angle for each of the rotational groups became significantly greater for each of the rotational groups (F = 2075.80, P = 0.000). Mean differences in AA measurement between preceding rotational groups (for example between 360 and 180, 540 and 360, 720 and 540) were statistically significant (mean difference ± 95% CL = 180.67 ± 59.30, 189.86 ± 58.30, 176.74 ± 23.70; P = 0.004, 0.002, <0.001 respectively). The clinical significance of these differences however is of the utmost importance for practical use in half-pipe snowboarding. The absence of overlapping Air Angle measurements between the four rotational groups ensures the measurement provides reliable classification of aerial acrobatics performed predominantly around a single axis during half-pipe snowboarding.
Figure 21. Raw acceleration data used to calculate air-time, Air Angle measurement and subsequent classification of aerial acrobatics. Data obtained from one half-pipe snowboard run performed by an Australian half-pipe snowboard athlete during 2007 AIS Micro-Tech Pipe Challenge, conducted at Perisher Blue Ski Resort, Australia.

Figure 22. Air Angle measurement (mean ± range) and relationship to four specific rotational groups (n = 216 acrobatic manoeuvres. * = statistical significance from the preceding rotational group (describing lower degree of rotation). Statistical significance was set at p < 0.05.

Of the utmost importance for the purpose associated with the development of this signal processing method however, was the absence overlapping AA measurement limits between the different rotational groups (Figure 22, Table 18). Whilst 95% confidence limits provide tighter upper and lower ranges of AA measurement for each rotational group, these statistically derived limits would generate incorrect acrobatic classification as a number of AA measurements could theoretically fall outside those ranges. The absence of overlapping AA measurement limits therefore affords some flexibility
outside the statistically derived likelihoods whilst still ensuring reliable classification of aerial acrobatics. Recommended ranges for the successful classification of half-pipe snowboarding aerial acrobatics using numerical integration of tri-axial rate gyroscope data are provided in Table 18.

**Table 18.** Air Angle (AA) measurement information associated with four half-pipe snowboarding specific rotational groups. Mean AA measurements are shown for each rotational group (reported as Mean ± SD). Mean differences and statistical significance are shown for each rotational group and the preceding lower rotational group (i.e. Between 360 and 180° rotational groups). Mean Differences are shown as mean ± 95% CL. The actual AA ranges established in this study and the AA ranges recommended for the successful classification of half-pipe snowboarding aerial acrobatics using numerical integration of tri-axial rate gyroscope data are also shown.

<table>
<thead>
<tr>
<th>Group (°)</th>
<th>n</th>
<th>Mean ± SD (°)</th>
<th>95% CL (°)</th>
<th>Mean Diff (°)</th>
<th>p</th>
<th>Actual Range (°)</th>
<th>Practical Range (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>180</td>
<td>159</td>
<td>152.13 ± 33.00</td>
<td>146.96 - 157.30</td>
<td>NA</td>
<td>NA</td>
<td>84 - 231</td>
<td>80 – 240</td>
</tr>
<tr>
<td>360</td>
<td>5</td>
<td>332.80 ± 47.41</td>
<td>273.93 – 391.67</td>
<td>180.67 ± 59.30</td>
<td>0.004</td>
<td>292 – 401</td>
<td>285 – 410</td>
</tr>
<tr>
<td>540</td>
<td>32</td>
<td>522.66 ± 44.52</td>
<td>506.61 – 538.71</td>
<td>189.86 ± 58.30</td>
<td>0.002</td>
<td>456 – 602</td>
<td>450 – 610</td>
</tr>
<tr>
<td>720</td>
<td>20</td>
<td>699.40 ± 40.04</td>
<td>681.44 – 717.36</td>
<td>176.74 ± 23.70</td>
<td>&lt;0.001</td>
<td>643 – 792</td>
<td>640 – 810</td>
</tr>
</tbody>
</table>

All confidence limits (CL) were performed using Excel spreadsheets (Hopkins, 2004). All confidence limits were set at 95% and statistical significance was set at p < 0.05. NA, Mean difference not provided as there is no preceding rotational group; °, Degrees.

### 3.5 Integration Into Elite Sport

The use of technologically-based automated objectivity can allow coaches, athletes and judges access to information pertaining to half-pipe snowboarding that has previously been unavailable. With the capacity to automatically quantify objective information on the half-pipe snowboarding key performance indicators, we conducted a concept competition, the 2007 Australian Institute of Sport (AIS) Micro-Tech Pipe Challenge. Ten elite-level male Australian half-pipe snowboarders were instrumented with wearable technology for the competition. This was one of the first half-pipe snowboarding competitions in the world to use automated objective information to award performance.

#### 3.5.1 Australian Institute of Sport (AIS) Micro-Tech Pipe Challenge

Table 19 shows the objective key performance variable information associated with TAT, AAT, HIAT, TDR, ADR, HIDR, HCDR, the subjectively judged competition
scores awarded for each run and the overall position for each athlete. A total of 18 cleanly completed runs out of a possible 30 were performed throughout the 2007 AIS Micro-Tech Pipe Challenge and not all athletes were able to perform more than one completely clean competition run. The scores shown in Table 17 were provided by the subjective judge throughout the competition and the objective key performance variable information was analysed post-competition with data obtained from inertial sensors and basic signal processing techniques established by this study.

Table 19. Key performance indicator information associated with each ‘cleanly completed run’ during the AIS Micro-Tech Pipe Challenge.

<table>
<thead>
<tr>
<th>Rider (bib)</th>
<th>Score (points)</th>
<th>Final Ranking</th>
<th>TAT (s)</th>
<th>AAT (s)</th>
<th>HIAT (s)</th>
<th>TDR (°)</th>
<th>ADR (°)</th>
<th>HIDR (°)</th>
<th>HCDR (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>9.20</td>
<td>1</td>
<td>6.28</td>
<td>1.26</td>
<td>1.52</td>
<td>3240</td>
<td>648</td>
<td>900</td>
<td>3240</td>
</tr>
<tr>
<td>8</td>
<td>9.00</td>
<td>2</td>
<td>7.78</td>
<td>1.30</td>
<td>1.46</td>
<td>2880</td>
<td>480</td>
<td>720</td>
<td>2520</td>
</tr>
<tr>
<td>2</td>
<td>8.50</td>
<td>3</td>
<td>6.94</td>
<td>1.39</td>
<td>1.48</td>
<td>2520</td>
<td>504</td>
<td>720</td>
<td>1260</td>
</tr>
<tr>
<td>8</td>
<td>8.00</td>
<td>-</td>
<td>7.76</td>
<td>1.29</td>
<td>1.38</td>
<td>2520</td>
<td>420</td>
<td>720</td>
<td>1440</td>
</tr>
<tr>
<td>2</td>
<td>7.70</td>
<td>-</td>
<td>6.36</td>
<td>1.27</td>
<td>1.46</td>
<td>2520</td>
<td>504</td>
<td>720</td>
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<tr>
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<td>7.60</td>
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<td>-</td>
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<td>432</td>
<td>720</td>
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<td>5</td>
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<td>1.37</td>
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<td>1.29</td>
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<td>270</td>
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<tr>
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<td>1.18</td>
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<tr>
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<td>1.26</td>
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<td>1980</td>
<td>396</td>
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<tr>
<td>6</td>
<td>4.80</td>
<td>9</td>
<td>5.86</td>
<td>0.98</td>
<td>1.4</td>
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<td>240</td>
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<td>-</td>
<td>6.32</td>
<td>1.05</td>
<td>1.24</td>
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<td>240</td>
<td>540</td>
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<td>-</td>
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<td>1.29</td>
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<td>-</td>
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<td>1.00</td>
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<td>240</td>
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<tr>
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<td>10</td>
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<td>1.48</td>
<td>1800</td>
<td>300</td>
<td>540</td>
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</tbody>
</table>

Data is shown in descending order of subjectively judged score. Not all athletes completed more than one ‘clean run’ throughout the competition. Subjectively judged scores were generated by the competition judge during the competition. Objective information pertaining to average air-time, average degree of rotation and highest individual air-time were analysed immediately post competition for the provision of the awards judged purely by objective measures. - - denotes second or third cleanly completed runs associated with a particular athlete (same bib number) that was not used to generate a final score or ranking as the run did not achieve that athlete’s best score. As previously described, an aerial acrobatic manoeuvre containing no sport specific rotational component still generates a value of 180 degrees as the athlete turns through approximately 180 degrees taking off and landing on the same half-pipe lip [4]. The first meaningful sport specific rotational acrobatic manoeuvre is a 360 degree rotation. A value of zero (0) in the HCDR column denotes that the athlete did not perform any aerial acrobatics that had rotational components in a consecutive series (more than one manoeuvre consecutively) i.e. All aerial acrobatics with a rotational component were performed singularly with straight airs (aerial acrobatics with no rotational component) in between each rotational acrobatic. AAT, Average Air Time; ADR, Average Degree of Rotation; HIAT, Highest Individual Air Time; HIDR, Highest Individual Degree of Rotation; TAT, Total Air Time; TDR, Total Degree of Rotation s, seconds; °, degrees.
There is a ‘practice community’ perception that air-time and degree of rotation play important roles in elite-level half-pipe snowboarding competition success however it is only ever assessed subjectively. The information generated by micro-technology following the 2007 AIS Micro-Tech Pipe Challenge provided objective support for this ‘practice community’ perception. Average air-time and average degree of rotation were selected as the most important key performance indicators within the 2007 AIS Micro-Tech Pipe Challenge based on their correlation to subjectively judged scores (AAT, $r = 0.48 \pm 0.38$, $p = 0.040$, $r^2 = 0.23$, $SEE = 1.67$, $n = 18$; ADR, $r = 0.87 \pm 0.14$, $p < 0.001$, $r^2 = 0.76$, $SEE = 0.94$, $n = 18$ respectively) (Table 12). Individually, average air-time and average degree of rotation can account for approximately 23% and 76% of the shared variance associated with an athlete’s subjectively judged score (Table 12, Figure 23A and Figure 23B respectively). When combined in a multiple linear regression equation (Equation 2-4, Table 13) however,

$$PS = 3.421 \text{AAT} + 0.011 \text{ADR} - 1.794$$  

Where:

$PS = \text{predicted score}$  

$AAT = \text{average air time}$  

$ADR = \text{average degree of rotation}$  

they show a very strong correlation and can account for approximately 80% of the shared variance associated with an athlete’s subjectively judged score within the 2007 AIS Micro-Tech Pipe Challenge ($r = 0.89 \pm 0.11$, $p < 0.001$, $r^2 = 0.80$, $SEE = 0.88$, $n = 18$) (Table 13, Figure 23C). It is important to note that the key performance variable of total air-time also showed a very large correlation (the same as average air-time) to an athlete’s subjectively judged score within this event however it was not selected as a variable entered into the multiple regression analysis as it was deemed to rely heavily on the number of aerial acrobatic manoeuvres performed throughout a routine; something not always associated with a high level of performance in competition by the half-pipe snowboard community.
Figure 23. Effect of average air time on score (a), effect of average degree of rotation on score (b), and multiple linear regression showing effect average air time and average degree of rotation (c) had on scores during AIS Micro-Tech Pipe Challenge, that is, PS according to \( PS=3.421 \text{ AAT}+0.011 \text{ ADR}–1.794 \); (–), Linear regression line; (--) 95 % confidence limits.
It is the combination of average air-time and average degree of rotation that is important in half-pipe snowboarding competition. In this particular competition average degree of rotation explained a large amount of the shared variance in scores (Table 12, Figure 23B). The combinations of average air-time and average degree of rotation that achieved specific subjectively judged scores within this competition are displayed in the 3D scatter plot in Figure 24. There are a number of things to note within this graph. 1) Average air-time and average degree of rotation do have an effect on competition scores however an athlete must achieve highly on both to be awarded high competition scores. In this event, a run with a combination of an average air-time over 1.2s and an average degree of rotation over 400 degrees provided an athlete with a score that placed them into one of the top 4 highest overall positions. 2) Athletes who focussed on average air-time only and not on the amount of rotations did not achieve high scores. For example; for an average air-time of 1.29s there is a large effect of average degree of rotation from 180 to 420 degrees which takes an athlete’s score from 4.2 to 8.0. In this particular competition average degree of rotation played a major role in successful outcomes. 3) An athlete needs a certain amount of air-time in order to be able to achieve high degree of rotations. Average air-times under 1.2s seemed to provide little opportunity to achieve high degree of rotations. 4) It was also interesting to note that for an average degree of rotation of approximately 250 degrees it did not seem to matter whether air-time goes from 1 to 1.4 s.

This study allowed a criterion (subjectively judged scores) referenced validation of predicted (using purely objective data) competition scores (Figure 25A) and rankings (Figure 25B) associated with 18 cleanly completed runs performed during the 2007 AIS Micro-Tech Pipe Challenge. The capacity of purely objective information used within the previously weighted prediction equation (Equation 2 – 3, Table 6) to generate scores and rankings associated with the 2007 AIS Micro-Tech Pipe Challenge is shown in (Table 20, Figure 25A) and (Table 20, Figure 25B) respectively. Scores predicted using equation 1 (practical measure) displayed a very large correlation to actual subjectively judged competition scores (criterion measure) achieved in the 2007 AIS Micro-Tech Pipe Challenge and could account for approximately 74% of the shared variance associated with subjective judging using purely objective information \((r = 0.86 \pm 0.14, p < 0.001, r^2 = 0.74, \text{SEE} = 0.97, n = 18)\). The mean bias between the criterion and practical measures of air-time was \(-0.65 \pm 0.59\) and the 95% confidence limits related to the mean bias were \(-1.24\) and \(-0.06\). The prediction equation (practical measure)
additionally displayed an almost perfect correlation to actual subjectively judged competition rankings (criterion measure) achieved in the 2007 AIS Micro-Tech Pipe Challenge and could account for approximately 82% of the shared variance associated with subjective judging using purely objective information ($r = 0.90 \pm 0.17$, $p < 0.001$, $r^2 = 0.82$, SEE = 1.38, $n = 10$). The mean bias between the criterion and practical measures of air-time was $0.00 \pm 0.77$ and the 95% confidence limits related to the mean bias were -0.77 and 0.77.

Figure 24. 3-D scatter plot displaying the effects that average air time and average degrees of rotation had on an athlete’s subjectively judged competition score during the 2007 Australian Institute of Sport Micro-Tech Pipe Challenge. It is the combination of average air time and average degree of rotation that is important in half-pipe snowboarding competition, and in this particular competition, the average degree of rotation explained a large amount of the shared variance in scores. Winning run shown in cluster 1 (performed by rider with bib number 10) in this competition achieved an average air time and an average degree of rotation of 1.26 s and 648 degrees, respectively. Run achieved only equal eighth-highest average air time, however, it achieved the highest average degree of rotation. Average degrees of rotation over 400 degrees, however, is only possible with average air times over 1.2 s on this particular half-pipe course (clusters 1 and 2). Cluster 1 (actual score 9.2): maximal Average Degree of Rotation (ADR), average Average Air Time (AAT); Cluster 2 (actual score 5–9): average ADR, average to high AAT; Cluster 3 (actual score 4–4.8): minimal ADR and minimal AAT; Cluster 4 (actual score 4.2–5.6): minimal ADR, average to high AAT.
Figure 25. Capacity of a previously-weighted multiple regression Equation 2 - 3 (PS = 11.424AAT + 10.013ADR - 2.223) derived from the 2006 Burton Open using objective data (practical measure) pertaining to average air time and average degree of rotation to predict actual subjectively-judged scores (a) and rankings (b) (criterion measure) achieved in the 2007 Australian Institute of Sport Micro-Tech Pipe Challenge, that is, PS according to Equation 2 - 3 divided by 3. (–), Linear regression line; (--) 95 per cent confidence limits.
Table 20. Competition scores (both actual and predicted) and associated final rankings (both actual, predicted, and athlete judged) achieved in the 2007 Australian Institute of Sport Micro-Tech Pipe Challenge.

<table>
<thead>
<tr>
<th>Rider (Bib no)</th>
<th>Actual Score</th>
<th>Actual Ranking</th>
<th>Predicted Score (PS)</th>
<th>Predicted Ranking (PR)</th>
<th>Athlete Judged Top 5 Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>9.20</td>
<td>1</td>
<td>6.85</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>9.00</td>
<td>2</td>
<td>6.28</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>8.50</td>
<td>3</td>
<td>6.73</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>8.00</td>
<td>-</td>
<td>6.00</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>7.70</td>
<td>-</td>
<td>6.29</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>7.60</td>
<td>4</td>
<td>6.00</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>7</td>
<td>7.20</td>
<td>-</td>
<td>5.78</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>6.50</td>
<td>-</td>
<td>6.25</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>5.60</td>
<td>5</td>
<td>5.39</td>
<td>6</td>
<td>-</td>
</tr>
<tr>
<td>1</td>
<td>5.50</td>
<td>6</td>
<td>5.32</td>
<td>7</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>5.20</td>
<td>7</td>
<td>4.63</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>5.00</td>
<td>8</td>
<td>5.77</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>4.80</td>
<td>9</td>
<td>4.02</td>
<td>10</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>4.60</td>
<td>-</td>
<td>5.10</td>
<td>8</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>4.50</td>
<td>-</td>
<td>4.31</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>4.20</td>
<td>-</td>
<td>4.96</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>4.00</td>
<td>-</td>
<td>4.12</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>9</td>
<td>3.40</td>
<td>10</td>
<td>4.96</td>
<td>9</td>
<td>-</td>
</tr>
</tbody>
</table>

Athletes perceived the top 4 competition places exactly the same way as the subjective judge, while rankings derived by micro technology and the objective prediction equation (predicted rankings) switched the second and third rankings. Prediction equation also ranked the first and fourth positions the same way as the athletes and the subjective judge. Interestingly, the athletes perceived the fifth ranking position exactly the same way as micro technology and the objective prediction equation, while the subjective judge ranked that particular run to be in eighth position. (–), second or third cleanly-completed runs associated with a particular athlete (same bib number) that was not used to generate a final ranking as the run did not achieve that athlete’s best score.

3.6 Sociological Impact

The integration of technology and the associated quantification of specific facets of sporting disciplines can have unintended consequences, often effecting change beyond its original purpose. These changes should be preceded with comprehensive discussions about what future is sought for a specific sport and where limits might be drawn on the changes. This study is a result of a progressive partnership ideology and has allowed the snowboarding community a forum to describe its perceptions on the impact of the automated performance assessment concepts and possible technological change this thesis proposes for their sporting discipline. This study therefore investigated the snowboard ‘practice community’’s perception to recent technological research.

3.6.1 Coaches And Athletes

This study investigated the perception of a sample of elite-level half-pipe snowboard coaches and athletes to the integration of automated objective information into
performance assessment criteria. Table 21 shows the six axial codes (dimensions) and twenty selective codes (sub-dimensions) related to three major themes (open codes) that emerged during the interview process. The major themes were: 1) The State of the Current Subjective Judging System, 2) Automated Feedback and Objective Judging System, and 3) Future Direction of the Sport.

**Table 21. Cultural Dimensions (Axial and Selective Codes)**

<table>
<thead>
<tr>
<th>Strengths of the Current Subjective Judging System</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Subjective perception of style and overall run execution</td>
</tr>
<tr>
<td>2. Allows athletic freedom of expression</td>
</tr>
<tr>
<td>3. Well trained judges with experience in the sport</td>
</tr>
<tr>
<td>4. Improvement on the gymnastics model of judging</td>
</tr>
<tr>
<td>5. Multinational judging panel</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Weaknesses of the Current Subjective Judging System</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Subjective perception of style and overall run execution</td>
</tr>
<tr>
<td>2. Expansive criteria displayed as one measurement – termed ‘Overall Impression’</td>
</tr>
<tr>
<td>3. Memory board short hand time constraints during judging</td>
</tr>
<tr>
<td>4. Limited access to experienced and high level judges</td>
</tr>
<tr>
<td>5. Increased population of athletes reaching ‘optimal performance’</td>
</tr>
<tr>
<td>6. Subjective judging error in aerial amplitude perception</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Replace Subjective Judging with Automated Objective Judging</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Removal of subjective perception of style and overall run execution</td>
</tr>
<tr>
<td>2. Removal of athletic freedom of expression</td>
</tr>
<tr>
<td>3. Generation of incorrect results</td>
</tr>
<tr>
<td>4. Separation from what is valued in the sport</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Integration of Both Subjective and Objective Methods in Judging Protocols</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Accurate KPV information perceived as beneficial</td>
</tr>
<tr>
<td>2. Objective information beneficial as judging aid (automatic memory board)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Possible Cultural Perception of Automated Judging</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Positive if integrated with current subjective system</td>
</tr>
<tr>
<td>2. Negative if used as the only measure of performance</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>The Consensus on Future Direction of the Sport</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Freedom of expression and athletic individuality culminating in well executed and stylish performances</td>
</tr>
</tbody>
</table>

### 3.6.2 World Cup Competition Judges

This study investigated the perception of a sample of elite-level half-pipe snowboard competition judges to the integration of automated objective information into
performance assessment criteria. Table 22 shows the 8 axial codes (dimensions) and 42 selective codes (sub-dimensions) related to 5 major themes (open codes) that emerged during the interview process. The major themes were: 1. Snowboarding’s Underlying Cultural Ethos 2. Snowboarding’s Underlying Self-Annullating Teleology 3. Technological Objectivity 4. Concept Management 5. Coveted Future Directions. Interview quotes are used within discussion (shown in italics) to highlight significant ‘practice community’ opinion.

Table 22. Cultural dimensions and sub-dimensions (Axial and Selective Codes) associated with the four major themes.

Athletic Freedom

1. Athletic freedom of expression
2. Freedom to showcase athletic individuality
6. Athlete driven progression
3. Athlete in control of competition performance
4. Minimal set criteria in competition
5. Subjective perception of style and overall run execution
6. Snowboarding’s soul / spirit / style / artistic merit
7. Non-conformist nature of snowboarding

The Existence of a Self-Annullating Teleology

8. An imminent threat to judging reliability
9. A distant threat to judging reliability
10. A currently occurring phenomenon
11. A negative aspect of the sport
12. A positive aspect of the sport
13. A theory without any relevance in snowboarding

Objective Performance Indicators

14. The importance of air-time and amplitude
15. The difference between air-time and amplitude
16. The diminishing importance of degree of rotation
17. The negative aspects of the ‘spin to win’ approach
18. The benefit of objective information on each individual trick
19. Subjective perception of style and run execution

Theoretical Objective Weighting

20. Theoretical KPV percentages in amalgamated judging system
22. No objective information should constitute any part of score
23. Opposition to solely objective assessment
24. Minimisation of automated technology’s role in generating scores

Technology’s Potential Role In Snowboarding

25. Automating memory boards
26. Simplification of judging process
27. Beneficial in unfavourable environmental conditions
28. Beneficial where snowboard half-pipes increase in length
29. Beneficial in athlete score protest situations
30. The importance of objective ‘revert’ classification

**The Negative Impact of Technology on Snowboarding**

31. Opposition to integration of technological objectivity
32. Removal of snowboarding’s underlying cultural ethos / spirit / soul
33. Potential for removal of athletic freedom of expression
34. Removal of what the ‘practice community’ values within the sport
35. Forced integration on a ‘practice community’ not consulted
36. Potential to push athletes away from competition

**Progressive Partnership Ideology**

37. Scepticism toward integration of technological objectivity
38. The need to assess athlete perceptions and coveted direction
39. The capacity of the judging system to direct competition riding

**Snowboarding’s Future Directions**

40. Sport retains cultural ethos and athletic freedom of expression
41. Sport remains partitioned from traditional sporting conventions
42. Sport retains competitive criteria that athletes value
4 DISCUSSION

Once considered the pastime of social misfits and subversive nomads reneging on adult responsibilities, snowboarding has fast become a premier elite sporting discipline, regardless of the current, underlying antiauthoritarian and counterculture ideology it exudes. The sport of snowboarding is currently juxtaposed between its traditional ideals of freedom, hedonism and rebellion and the athletic ideals of discipline, control, and continual performance enhancement. The dissertation essentially lays the foundations for a bridge between two vastly disparate cultures; one associated with sport science and its quest to enhance athletic performance and the other associated with snowboarding, a sport with an underlying anarchistic and antiauthoritarian ideology. Although undertaken with consideration of the sport’s traditional philosophies and emphasis of the practice community on the more stylistic and subjective aspects of snowboarding performance, this body of work examines the use of technology to introduce relevant, objective methods to improve athletic performance and the reliability associated with the assessment of that performance. Elite half-pipe snowboarding performance data was collected over three winter seasons from 2006 to 2008 including a Winter Olympic Games and was used to define and establish objective key performance indicators (KPI’s) that account for a large percentage of shared variance in subjectively judged competition scores. These findings were then applied to customise wearable sensor technology to develop an automated performance feedback system suitable for everyday use with the ability to quantify accurate and reliable data on these sport specific KPI’s. This system was subsequently used to run one of the first electronically judged half-pipe snowboard competitions in the world. The impact of sport science and new technology on the sport of snowboarding was additionally assessed and although athletes, coaches and competition judges are not totally opposed to the idea, there is a strong perception that further development and integration of this concept be conducted in close association with core community members and be controlled from within the sport.

4.1 Key Performance Indicators

Like other sports that rely on subjective performance assessment the methodology underpinning how snowboard coaches routinely assess athletic progression and judges score competitions is open for debate, discussion and improvement. For coaches, athletes and judges involved in elite-level half-pipe snowboarding, performance assessment based on objectivity is something that is yet to be utilised to its full
potential. Through the use of video based analysis this thesis defined objective key performance indicators (KPI’s) specific to half-pipe snowboarding, established their relationship to subjectively judged scores, provided evidence of a longitudinal trend of continually increasing performance levels at the elite level, defined the smallest worthwhile change (SMC) required for elite level competition performance enhancement, and compiled performance information associated with the highest level half-pipe snowboard competitions. In doing so this study demonstrated that an in-field derived video based analysis can be used to calculate relevant and practical objective information pertaining to the sport of half-pipe snowboarding.

4.1.1 Competitive Variance Explained Objectively

Average air time (AAT) and average degree of rotation (ADR) are the strongest individual sport specific performance indicators associated with success in elite-level half-pipe snowboarding competition. Objective data associated with AAT and ADR alone show strong correlation with subjectively judged scores during the Burton Open Australian Half-Pipe Championships from 2006 to 2008, during three consecutive international Fédération Internationale de Ski (FIS) World Cup competitions in 2006 (the qualifying competition circuit for the Winter Olympic Games), and during the AIS Micro-Tech Pipe Challenge in 2007 (Table 5, Table 8, and Table 12 respectively). When the objective information associated with AAT and ADR are combined using multiple regression (enter method), it is additionally possible to explain a large proportion of subjectively judged scores in all half-pipe snowboarding competitions assessed by this study with no reference to style or execution. During the Burton Open Australian Half-Pipe Championships, objective information on AAT and ADR combined could account for approximately 71 to 77 percent and 80 to 94 percent of the shared variance in men’s and women’s subjectively judged competition scores respectively (Table 6). During three consecutive FIS World Cup Half-Pipe Snowboard Competitions in 2006, objective information on AAT and ADR combined could account for approximately 66 to 75 percent and 74 to 94 percent of the shared variance in men’s and women’s subjectively judged competition scores respectively (Table 9). Similarly objective information on AAT and ADR combined could account for approximately 80 percent of the shared variance in subjectively judged competitions scores during the AIS Micro-Tech Pipe Challenge in 2007 (Table 13).
4.1.2 Magnitudes of Difference Between Success And Failure

Furthermore there are major differences in athletic performance of AAT and ADR between athletes achieving top three rankings (T3) and those placing outside the top three during (OT3) the Burton Open Australian Half-Pipe Championships and the AIS Micro-Tech Pipe Challenge. Similarly there are major differences in athletic performance of AAT and ADR between Finalists and Qualifiers during three consecutive FIS World Cup Half-Pipe Snowboarding Competitions. An adopted approach of magnitude-based inferences was used to further analyse differences in KPI performance between these groups. Magnitude of difference between athletic performances was established with a standardised effect size (ES) with 95% confidence limits. The criteria for interpreting effect size were: <0.2, trivial; 0.2-0.6, small; 0.6-1.2, moderate; 1.2-2.0, large; and > 2.0, very large (Batterham & Hopkins, 2006). This study has shown that for the most part, there are key differences (with at least moderate to very large effect sizes) in the group means of AAT and ADR between those athletes that achieved top three (T3) competition rankings and those that did not (OT3) during the Burton Open Australian Half-Pipe Championships (Table 7) and the AIS Micro-Tech Pipe Challenge (Table 14). Likewise there are key differences (with at least moderate to very large effect sizes) in the group means of AAT and ADR between Finalists and Qualifiers competing in FIS World Cup Half-Pipe Snowboarding Competitions (Table 10).

4.1.3 Smallest Worthwhile Changes At The Elite Level

When monitoring progression of athletic performance, it is important to take into account the magnitude of the smallest worthwhile change in performance. For elite athletes competing in sports as individuals, the smallest worthwhile change in performance is about half the typical variation in an athlete's performance from competition to competition. This study has established the variation in AAT and ADR performance from competition to competition and in doing so presents the smallest worthwhile changes required for a half-pipe snowboard athlete to enhance their competitive success. The within-subject variation in AAT and ADR performances achieved by elite half-pipe snowboard athletes was calculated from the data pertaining to the two consecutive FIS World Cup Half-Pipe Snowboarding Competitions conducted in Leysin Switzerland on the 18th and 19th January 2006. For the most part there is a small degree of variation in AAT and ADR performances from competition to
competition. The coefficient of variation (CV) associated with AAT and ADR performance between these two competitions was 4.42 percent and 5.14 percent for male athletes respectively and 4.03 percent and 15.48 percent for female athletes respectively (Table 11). For the most part, the within subject variation between competitions is small (~5%) for both AAT and ADR. Elite-level half-pipe snowboarders therefore possess a high level of performance consistency between competitions. The large coefficient of variation associated with female performance of ADR between these two competitions however is theorised to be a result of the emergent competitor base and the embryonic and continually evolving levels of performance in women’s snowboarding at the time.

The Smallest Worthwhile Change (half the Coefficient of Variation) is the average change in performance of AAT and ADR required to increase or decrease an athlete’s final competition ranking. For male half-pipe snowboarders, an absolute change in AAT by 0.03s and an absolute change in ADR by 12.92° (on average) has the potential to alter their final competition ranking (Table 11). It is important to note that these values are associated with the two strongest key performance indicators AAT and ADR and so for coaches applying these values in terms of a complete competition run (which consists of approximately six aerial acrobatic manoeuvres) a change in total air time (TAT) and total degree of rotation (TDR) by approximately 0.18s (~0.20s) and 77.52° (~90° in terms of quantised classification of aerial acrobatics) is the smallest increase or decrease in KPI performance required to alter a competitors final competition ranking. In terms of air time, exploiting this finding is straightforward. Small, consistent increases in air time performance during each aerial acrobatic manoeuvre over the course of a competition run can improve an athlete’s final ranking. In terms of degree of rotation (of which the smallest sport specific increase or decrease is 180°), an extra 180° rotation achieved somewhere within a competition run has the potential to enhance competition performance. For female half-pipe snowboarders, an increase of 0.02s in AAT and 23.89° in ADR has the potential to either increase or decrease final competition rankings (Table 11). Similarly, for female half-pipe snowboarders, an increase in TAT of approximately 0.12s and the completion of an extra 180° rotation somewhere within a run has the potential to also improve their competition ranking.
4.1.4 Criterion References For Half-Pipe Performance

Objective analysis of KPI’s in the manner established by this study can additionally generate criterion references of performance for particular competitions, allowing coaches and athletes to accurately define performance goals and thereby exploit the factors most highly associated with success. On average, male athletes cleanly completing a competition run during the Burton Open Australian Half-Pipe Championships with a combination of an AAT and an ADR of 1.39s and 729.00°, 1.44s and 726.75°, and 1.52s and 742.50° were provided a score that placed them into the top three final rankings in 2006, 2007 and 2008 respectively (Table 7). On average female half-pipe athletes cleanly completing a competition run with a combination of an AAT and an ADR of 1.16s and 387.00°, 1.10s and 362.14°, and 1.14s and 423.86° were provided a score that placed them into the top three final rankings in 2006, 2007 and 2008 respectively (Table 7). During the concept competition, the AIS Micro-Tech Pipe Challenge (where the field was comprised of 10 elite-level Australian snowboarders), a competition run with a combination of an AAT and an ADR of 1.32s and 544.00° respectively would have provided an athlete with a final competition score that placed in the top three final rankings (Table 14). In terms of FIS World Cup half-pipe snowboarding competition male athletes on average, cleanly completing a competition run with a combination of an AAT and an ADR of 1.54s and 606.50°, 1.52s and 549.50°, and 1.58s and 541.00° were provided a subjectively judged score that placed in the Finals (top twelve) in Kreischberg Austria (9th January 2006), Leysin Switzerland (18th January 2006) and Leysin Switzerland (19th January 2006) respectively (Table 10). On average female half-pipe athletes cleanly completing a competition run in FIS World Cup half-pipe snowboarding competition with a combination of an AAT and an ADR of 1.25s and 360.00°, 1.18s and 307.14°, 1.11s and 378.00° were provided a subjectively judged score that placed in the Finals (top twelve) in Kreischberg Austria (9th January 2006), Leysin Switzerland (18th January 2006) and Leysin Switzerland (19th January 2006) respectively (Table 10).

Additionally, this study objectively assessed the performances associated with the finals of the 2006 Winter Olympic Games Half-Pipe Snowboarding Competition. Although a highly contentious notion (as previously established), for most national sporting organisations, the Olympic Games is considered the highest level of half-pipe snowboarding competition and is therefore their primary competitive focus. In 2006, the Winter Olympic Games Half-Pipe Snowboarding Competition could therefore be
considered as the ‘gold standard’ level of performance for our purpose. In terms of the strongest key performance indicators associated with competition performance (as established during the Burton Open Australian Half-Pipe Championships, three consecutive FIS World Cup Half-Pipe Snowboarding Competitions and the AIS Micro-Tech Pipe Challenge), we established that on average, male athletes competing in the final of the 2006 Winter Olympic Games Half-Pipe Snowboarding Competition achieved an AAT of 1.70 ± 0.07s and an ADR of 733.64 ± 40.52° (Mean ± SD). Similarly female athletes achieved an AAT of 1.40 ± 0.12s and an ADR of 444.00 ± 64.49° (Mean ± SD). In 2006, half-pipe snowboarding performances that achieved these objective levels were sufficient to make the finals in Olympic competition (Table 15). At the time, this finding could provide a basis for developing and implementing individual athlete strategy and team selection criteria for half-pipe snowboard coaches and athletes focused on achieving success at the highest level.

4.1.5 Continual Evolution Of Competitive Performance

The levels of performance and perhaps the relationships between AAT and ADR in elite half-pipe snowboarding competition will no doubt evolve. There was a longitudinal trend of increasing AAT and ADR performances by male athletes over three years of the Burton Open Australian Half-Pipe Championships. Although not all mean differences in AAT and ADR performances were statistically significant, the trend was robust in men’s competition. There was a statistically significant increase in both AAT and ADR performance by male finalists between years 2006 and 2008 in the Burton Open Australian Half-Pipe Championships (Figure 15). The performances of female athletes during the three years this competition was assessed on the other hand showed no such trend and there were no statistical significant differences associated with AAT and ADR performances between any year of the competition. Whilst men’s half-pipe snowboarding performance levels were well established at the time this study was conducted and showed increasingly levels of performance, women’s half-pipe snowboarding performance was still evolving and this evolution was consistent with an emergent competitor base. The longitudinal increases in male performances however establish the continually evolving nature of half-pipe snowboard performance and it is theorised that the female competitor base will increase and subsequently begin to show similar changes in performance in the future. This type of performance analysis will therefore need regular updating in the future in order to maintain the relevance of the
objective KPI information this study promotes as an innovative performance assessment solution for the sport of half-pipe snowboarding.

### 4.1.6 Applications For Objectivity In Elite Snowboarding

These findings are novel, sport specific, practically relevant to elite-level half-pipe snowboarding performance and have significant implications for training and competition performance assessment in the sporting discipline. This study has established that AAT and ADR alone correlate strongly to subjectively judged competition scores and that when these two individual KPI’s are combined using multiple regression, they can account for a large component of elite-level competition success, irrespective of style and execution. The fact that one hundred percent of the shared variance in subjectively judged scores could not be explained using purely objective information however should not be considered a weakness of an this approach but a strength, as the subjective components of style and execution should never be removed from the sport of half-pipe snowboarding. The large amount of shared variance in competition success explained by objective measures and the existence of key differences in the performance of AAT and ADR between athletes that are successful in competition and those that are not will allow the application of half-pipe snowboarding specific objective information in training and competition performance assessment. Utilising sport specific information such as that presented in this study, a coach can provide an environment that is conducive to optimum learning by augmenting the feedback that athletes receive and thereby take appropriate measures to achieve specific levels or performance.

Augmented and objective feedback provided to coaches, athletes and judges however is relevant only if there is knowledge of the ultimate performance goal. The strength of the relationships between air time, degree of rotation and competition success, the objective data pertaining to specific air time and degree of rotation performances needed to reach the podium in elite competition and the smallest worthwhile performance changes required to enhance competitive success can be used by coaches, athletes and judges to exploit the factors most highly associated with success. For coaches and athletes who did not perform well in these competitions, it is believed the objective performance information established in this study would provide specific objective training targets for future competitions conducted on the same or similar courses, enabling athletes to modify their movements and produce optimum performance. For
competition judges, this sport specific objective information may have the potential to assist their current subjective performance assessment protocols, minimising potential bias and judging corruption, provided the information can be provided accurately, reliably and quickly.

In light of the longitudinal increases and continually evolving nature of half-pipe snowboarding, this type of analysis and the associated quantification of training and competition performances will need routine updating to remain relevant to the sport. The major issue with continual assessment and regular updating of objective information associated with half-pipe snowboarding performance is that the method initially used by this study (video based analysis) is labour intensive and associated with a large delay in information feedback. This study therefore investigated the potential of automatically quantify this information in a timely manner by using technology and in so doing, ensure that routine monitoring of half-pipe snowboarding performance can be accomplished accurately, reliably, and with ease.

### 4.2 Sports Technology

The video analysis method used in this study to calculate objective information on half-pipe snowboarding performance was labour intensive and associated with a large time delay in providing feedback information to coaches, athletes and judges. Advances in information technology tailored for a multitude of sports has however made it possible to improve the type of feedback and the speed at which it is provided to coaches and athletes during training and competition. Modern technology in fact has had such a profound impact on sport that many athletes and coaches now consider information derived from technological advances as an invaluable resource. This however is not the case within the sporting discipline of half-pipe snowboarding. Coaches, athletes and competition judges still rely on subjective performance assessment and for the most part, are unaware of the benefits an objective approach could provide. There is also a lack of instrumentation, which often enters the sports scene very slowly however in the case of half-pipe snowboarding, there also is a very limited amount of technology specifically designed to quantify important facets of the sport. Laboratory based performance assessment of half-pipe snowboarding (and snowboarding in general) is currently impossible and the sport is therefore well placed to take advantage of any pursuit focussed on the capacity to obtain ecologically valid performance data in the field. Half-pipe snowboarding however is also at the mercy of those developing field
based quantification methods to generate a product customised specifically for the sport and that quantifies information that is relevant to performance.

4.2.1 Technology Customised For Half-Pipe Snowboarding

The monitoring system developed by this study focussed on variables previously established to impact elite half-pipe snowboarding performance and could quantify these variables quickly without restricting or altering an athlete’s normal movement by weight or tether. Specifically, this study customised wearable sensor technology (comprised of tri-axial accelerometers and tri-axial rate gyroscopes) and developed signal processing techniques to produce an automated performance feedback system suitable for use routine quantification of air time and degree of rotation in half-pipe snowboarding training and competition environments. The customization process therefore consisted of three parts. 1. Collection of both video data (criterion reference) and inertial sensor data (practical method) from elite-level performance during half-pipe snowboarding training and competition runs. 2. Development of mathematical signal processing techniques to automatically quantify objective information on half-pipe snowboard specific key performance indicators (air time and degree of rotation). 3. Validation of those signal processing techniques against the video based criterion reference and ‘practice community’ rules for aerial acrobatic classification.

4.2.2 Automatic Air Time Quantification

This study has established that air time (specifically average air time) plays a important role in half-pipe snowboarding competition success and promotes the use of this objective information as a method to enhance performance assessment and performance feedback in coaching and judging environments, allowing coaches and judges to shift their focus to the more stylistic aspects of performance. In order to do so however, objective information associated with aerial acrobatic air time must be provided in a timely manner and by using a system that does not restrict an athlete’s normal movement patterns or performance focus. The movement patterns associated with half-pipe snowboarding are biomechanically complex however the rotations in longitudinal axes and the movement directions in the orthogonal axes could describe the movement for our application. This study demonstrates that complete half-pipe snowboarding runs performed by instrumented athletes generate a distinct, repeatable tri-axial accelerometer pattern displaying elevated accelerations in both the A1 (forward / backward) and A3 (upward / downward) orthogonal axes throughout the take off and
landings and a period of minimal force readings throughout the air time phase associated with aerial acrobatic manoeuvres (Figure 16). The quantification of air time and degree of rotation was focussed on signal processing of the distinct patterns generated by inertial sensor data with gross reference to these sensor axes. The rapid and opposing changes in A1 and A3 acceleration occur when athletes progress up the vertical snowboard half-pipe transitions, out of and eventually re-enter the half-pipe transitions during the performance of aerial acrobatic manoeuvres. The properties of accelerometers are such that upon coming into contact with the earth’s surface following a period of air-time, there is a brief period of augmented activity and high force readings from which aerial acrobatic landings can be detected. This is a novel finding and provided the basis for the development of automated methods of air time quantification using tri-axial accelerometer outputs and signal processing techniques on half-pipe snowboarding data.

Although there were a number of signal processing techniques trialled throughout this study, the two most promising methods are detailed within this thesis. Validation of Method One showed an almost perfect correlation ($r = 0.92 \pm 0.03$, $p$ value $< 0.0001$, $r^2 = 0.85$, $SEE = 0.06$, $n = 102$, $PE = 1.006AT + 0.002$) between the criterion (video based analysis) and practical (accelerometer based signal processing technique) methods (Table 17, Figure 17). The mean bias between the criterion and practical measures of air-time was $-0.01 \pm 0.01$s (Table 17) and the 95% confidence limits related to the mean bias were $-0.02$s and $-0.00$s (Figure 18). Approximately 97% (97.10%) of the practical measures lie within $\pm 0.15$s of the criterion measure (0.15s was deemed an acceptable error for automatic air time quantification). The signal processing technique used for Method One however generated two false positives (detecting and quantifying an air time for a non-existent aerial acrobatic manoeuvre) and twenty five false negatives (failing to detect and quantify an air time for aerial acrobatic manoeuvres performed in the study). Although Method One displayed a high level of accuracy it additionally showed a high level of unreliability. Improved accuracy will always be a focus however the inability of Method One to quantify air times for aerial acrobatic manoeuvres without the generation of false positives and false negatives severely limits its ability to be successfully integrated into half-pipe snowboarding training and competition environments.

Validation of Method Two showed a very large correlation ($r = 0.78 \pm 0.08$, $p$ value $< 0.0001$; $r^2 = 0.61$, $SEE = 0.08$, $n = 92$, $PE = 0.748AT+0.302$) between the criterion
(video based analysis) and practical (accelerometer based signal processing technique) methods (Table 17, Figure 19). The mean bias between the criterion and practical measures of air-time was -0.03 ± 0.02s and the 95% confidence limits related to the mean bias were -0.01s and -0.05s (Figure 20). There was however, indication of a small degree of non-uniformity in the residuals (heteroscedasticity) shown for example by the bias of 0.05s ± 0.04s at the low end of the air-time scale (1.00s of air-time) and the bias of -0.10s ± 0.04s at the high end of the air-time scale (1.60s of air-time). There was however, no significant relationship in the non-uniformity of this bias. It seems the non-uniformity was generated by outliers rather than being a systematic effect of increasing air-time. As such the utilisation of a calibration equation is of no use in correcting the slight non-uniformity within this data sample. Approximately 95% (94.57%) of the practical measures lie within ± 0.15s of the criterion measure. Method Two however was able to detect 100 percent of the aerial acrobatic manoeuvres performed during this study and generated zero false positives and zero false negatives. Although Method Two displayed a lower level of accuracy than Method One, the capacity of the practical method to calculate air-time for 100 percent of aerial acrobatic manoeuvres where 94.7% of measures fell within ± 0.15s of the criterion (where 0.15s was deemed an acceptable error for automatic air time quantification) would allow successful integration of this Method into half-pipe snowboarding training and competition environments. Future research will focus on improving the accuracy, reliability and the processing time associated with methods of automatic quantification of air time using tri-axial accelerometers.

4.2.3 Automatic Degree of Rotation Quantification

As established by this study, air-time is not the only objective performance variable that impacts on an athlete’s subjectively judged competition score. This study has provided evidence that average degree of rotation associated with half-pipe snowboard manoeuvres also contributes strongly to competition scores. The development, validation and integration of a signal processing technique to classify the degree of rotation associated with half-pipe snowboarding aerial acrobatic manoeuvres was a logical extension of the research focussed on quantifying air-time by using technology. This study investigated the effectiveness of processing rate gyroscope data by numerical integration, in combination with a previously documented method of quantifying acrobatic air-time, to classify half-pipe snowboarding aerial acrobatics into sport specific rotational groups. The terminology used by the ‘practice community’ to
describe acrobatic rotation is based upon an approximation of angular displacement and the relationship between direction of travel at take-off and landing. Provided rotations are performed predominantly around a single axis, the signal processing method presented in this paper provides reliable classification of aerial acrobatics.

Figure 21 shows the signal processing technique output (Air Angle) associated with a number of different aerial acrobatic manoeuvres performed during a single half-pipe snowboarding run. Average Air Angle for each of the rotational groups became significantly greater as aerial acrobatic complexity increased (F = 2075.80, P = 0.000). Figure 22 shows that the mean differences in AA measurement between preceding rotational groups (for example between 360° and 180°, 540° and 360°, 720° and 540°) were statistically significant (mean difference ± 95% CL = 180.67° ± 59.30°, 189.86° ± 58.30°, 176.74° ± 23.70°; P = 0.004, 0.002, <0.001 respectively). The clinical significance of these differences however is of the utmost importance for practical use in half-pipe snowboarding. The absence of overlapping Air Angle measurements between the four rotational groups ensures the automatically derived measurement provides reliable classification of aerial acrobatics performed predominantly around a single axis during half-pipe snowboarding. The AA ranges this study recommends for the successful classification of half-pipe snowboarding aerial acrobatics using numerical integration of tri-axial rate gyroscope data are provided in Table 18.

Developing the capacity to automatically classify aerial acrobatics was initiated based on the relevance of this information and a focus on integrating objectivity into a sport that has relied on subjective performance assessment since inception. Alongside the previously documented ability to calculate air-time, the automation of aerial acrobatic classification is theorised to provide enhanced performance assessment during training and competition; freeing coaching and judging staff to focus intently on the subjective execution and overall composition of acrobatics incorporated into half-pipe snowboarding routines. At present however, the signal processing method documented cannot assess exact degree of rotation, direction of travel, direction of rotation or the presence of inversion and is focused upon acrobatics that are performed predominantly around a single axis. Subsequently, the impact on current performance assessment protocols is theorised to be limited. Coaches and judges are trained to recognise aerial acrobatics and whilst the classification system documented can automate that process, it does not provide any additional information to what can already be determined with the naked eye.
One of the problems with this method was an inability to reliably classify acrobatics performed in more than one axis, such as those that incorporate inversion. This was revealed in acrobatics above 540 degrees of rotation. Acrobatics up to 540 degrees (apart from a few specific inverted manoeuvres) are predominantly performed in one axis (yaw) as they are undemanding of most elite athletes. As the degree of rotation increases however, athletes begin to employ inversion (and hence another axis of rotation) in order to successfully complete required rotation. It is upon processing these inverted manoeuvres that the method documented in this study fails to reliably classify aerial acrobatics. Signal processing of inverted aerial acrobatic manoeuvres (all of which were 720 degree rotations) generated AA measurements that often fell below recommended ranges and were subsequently classified incorrectly (into a lower rotational group than the descriptive terminology). This is the primary reason (in addition to limited samples of inverted 720 degree rotations) this study focussed upon acrobatics performed predominantly in one axis. All acrobatics comprise at least some rotation in all axes (unproblematic for classification via AA measurement) however aerial acrobatics incorporating inversion as a major technical component will require more advanced signal processing for accurate and reliable classification.

Although the method is intuitively appealing (providing a derived measurement with the same units as rotational group terminology), it is unnecessary for acrobatic classification. Proportionality of angular velocity to angular displacement should theoretically allow classification of acrobatics in the same manner, albeit with a different unit of measurement, by accumulating and summatng discrete, absolute angular velocity measurements over air-time. Furthermore, summation of angular displacements over three axes is void of physical reference, is essentially an arbitrary measurement and is the reason for the method’s failure to classify acrobatics incorporating inversion. It does however, theoretically provide an indication of acrobatic complexity and is a platform for future refinement of this concept.

Considering the ‘practice community’ perceives some inverted manoeuvres to be an easier method of achieving higher degree of rotation, there is some potential for the AA measurement to gauge acrobatic complexity. Future research however, will focus on the capacity to calculate objective information on exact degree of rotation, direction of travel, direction of rotation and presence of inversion.
4.2.4 An Innovative Performance Assessment Solution

With strong, positive correlations between sport specific key performance indicators such as average air-time, average degree of rotation and competition scores, and the established capacity to automatically quantify this information by using technology and signal processing, it is intuitively appealing to propose a performance assessment protocol for half-pipe snowboarding that incorporates objective data. This thesis suggests that a Micro-Electrochemical System (MEMS) sensor based, augmented feedback system could assist coaches and judges by providing accurate, electronic ‘memory boards’ (a record of an athlete’s run characteristics currently written by hand) by quantifying and displaying objective information on sport specific indicators such as air time and degree of rotation (information currently unavailable to elite-level judges). This will enable both coaches and judges to focus solely on the execution and overall composition of aerial acrobatics incorporated into a competition run. For coaches and athletes, it is believed relevant objective performance information quantified by technology in a timely manner would provide enhanced preparation and competition performance analysis protocols. For competition judges, the objective information presented in this study has the potential to assist the current subjective performance assessment protocols and minimise any potential bias and judging corruption. Furthermore, this study proposes that the future of half-pipe snowboarding may best be guided a judging protocol that incorporates both objective and subjective criteria.

4.3 Integration Into Elite Sport

In many sports, objective information tailored for a specific discipline is unavailable due to lack of suitable instrumentation. The rationale for this is that instrumentation embedded into equipment is often constrained by rules, laws and regulations surrounding existing competitions, and instrumentation worn by athletes is often impeded by the size and mass of specific sensors and the necessity to be attached to the athlete’s body. These issues stifle the integration of innovative concepts with the potential to enhance both performance assessment and spectator immersion in many sporting disciplines. Furthermore, the major concern of many sporting communities is that improvements in sport science and technology possess a latent ability to remove the stylistic components out of a sporting discipline, effecting change beyond its original purpose and thereby reducing the magic of a performance to a series of mathematical equations. Regardless of these concerns, this study derived a concept half-pipe
snowboarding competition (Figure 26) to assess the potential benefits and additionally the potential negative consequences of its own innovative performance assessment proposal.

Figure 26. AIS Micro-Tech Pipe Challenge Half-Pipe Snowboard Competition Flier. As far as we can ascertain, this was the first snowboarding competition in the world to use automatically generated objective information associated with air-time and degree of rotation to award athletic performance.

4.3.1 The Innovative Competition

With the capacity to quickly and automatically quantify previously established objective information on key performance indicators strongly associated with half-pipe snowboard competition success, we conducted a concept competition, the 2007 Australian Institute of Sport (AIS) Micro-Tech Pipe Challenge (Figure 26). This competition was designed to evaluate whether the snowboard community would embrace a competition where results were in part determined by automated objectivity, explore the practical, logistical and technical challenges associated with conducting such an event, evaluate the relationship between subjective judging and results predicted
from objective information to see if prior research had ecological validity and explore the utility of incorporating technology to enhance the “fairness” of judging world class snowboard athletes. Based on previous findings established by this study we constructed a snowboard competition requiring athletes to compete whilst instrumented with inertial sensors. As far as we can ascertain, this was the first half-pipe snowboard competition in the world to use automated objective information to award athletic performance (Table 1).

4.3.2 The Automatically Quantified Data

Although coaches and judges are aware of the importance air-time and degree of rotation have on competition scores, most assess athletic performance during routine training sessions and in competitions respectively in a purely subjective manner. This competition allowed the correlation of individual objective key performance indicators including TAT, AAT, HIAT, TDR, ADR, HIDR, HCDR to a criterion reference (subjectively judged competition scores generated by a World Cup snowboard judge). The information quantified by micro-technology following the 2007 AIS Micro-Tech Pipe Challenge provided objective support for this ‘practice community’ perception. Average air-time and average degree of rotation were the strongest individual key performance indicators within the 2007 AIS Micro-Tech Pipe Challenge based on their correlation to subjectively judged scores (AAT, $r = 0.48 \pm 0.38, p = 0.040, r^2 = 0.23, SEE = 1.67, n = 18$; ADR, $r = 0.87 \pm 0.14, p < 0.001, r^2 = 0.76, SEE = 0.94, n = 18$ respectively) (Table 12).

Individually, average air-time and average degree of rotation can account for approximately 23% and 76% of the shared variance associated with an athlete’s subjectively judged score (Table 12, Figure 23A and Figure 23B respectively). It is important to note that the key performance variable of total air-time also showed a very large correlation (the same as average air-time) to an athlete’s subjectively judged score within this event however it was not selected as a variable entered into the multiple regression analysis as it was deemed to rely heavily on the number of aerial acrobatic manoeuvres performed throughout a routine; something not always associated with a high level of performance in competition by the half-pipe snowboard community. When AAT and ADR performances achieved by each athlete during the AIS Micro-Tech Pipe Challenge were combined in a multiple regression (enter method), they displayed a very large correlation with and could account for approximately 80% of the
shared variance in subjectively judged scores \( (r = 0.89 \pm 0.11, p < 0.001, r^2 = 0.80, SEE = 0.88, n = 18) \) (Table 13, Figure 23C). It is proposed the type of objective information generated by micro-technology during half-pipe snowboarding as shown during the AIS Micro-Tech Pipe Challenge could be used to enhance the current coaching protocols and provide a simple, effective objective method to monitor athletic performance progression.

For example objective information generated during the 2007 AIS Micro-Tech Pipe Challenge showed that although AAT and ADR did have an effect on subjectively judged scores, an athlete had to achieve highly in both components to produce successful competition performances. In this particular event, a competition run with a combination of an average air-time over 1.2s and an average degree of rotation over 400 degrees provided an athlete with a score that placed them into one of the top four highest overall positions. Furthermore athletes who seemed to focus only on average air-time and not on the amount of rotations they performed during their competition runs did not achieve high scores in this particular competition. Although ADR was a major factor determining competition performance in this event, it was also shown that an athlete needs a certain amount of air-time in order to be able to achieve high degree of rotations. We believe the information that can be generated by micro-technology (as shown during the 2007 AIS Micro-Tech Pipe Challenge) can be successfully utilised to assist coaches routinely monitor the performance of their athletes in a more objective manner and subsequently allow them to shift some of their subjective assessments toward the more stylistic components of half-pipe snowboarding performance.

4.3.3 The Automated Judging System

This study additionally explored the utility of incorporating objective information quantified by micro-technology and signal processing to enhance the “fairness” of judging world class snowboard athletes. From an Olympic perspective, subjective judging protocols are open for manipulation and corruption and there have been recent calls for system of judging to be introduced that is based upon more accurate, reliable and stringent measures, without stifling athletic freedom of expression. We have shown in this study that it is possible to utilise previously established weightings associated with the objective information on air-time and degree of rotation to predict current competition scores and rankings with no reference to the subjective components of style or execution. A retrospective analysis of AAT and ADR with previously established
weightings (from the 2006 Burton Open half-pipe event conducted on the same half-pipe) showed a very large correlation \( r = 0.86 \pm 0.14, p < 0.001, r^2 = 0.74, \) \( SEE = 0.97, \) mean bias = -0.69 ± 0.59, \( n = 18 \) with subjectively judged scores awarded in the 2007 AIS Micro-Tech Pipe Challenge (Table 20, Figure 25A). Furthermore these predicted scores accounted for approximately 74 percent of the shared variance in competition results. Additionally we could predict overall competition rankings with an almost perfect correlation with the actual competition rankings awarded in the AIS Micro-Tech Pipe Challenge \( r = 0.90 \pm 0.17, p < 0.001, r^2 = 0.82, \) \( SEE = 1.38, n = 10 \) and account for approximately 82 percent of the associated shared variance (Table 20, Figure 25B). Furthermore the athletes themselves perceived the top four competition results exactly the same as the subjective judge whilst rankings derived by micro-technology and the objective prediction equation ranked the first and fourth positions the same as the athletes and the subjective judge however switched the second and third rankings. Interestingly the athletes perceived the fifth ranking position exactly the same as micro-technology and the objective prediction equation whilst the subjective judge ranked that particular run in eighth position.

Although our predictions of overall scores and rankings associated with this competition were good there was still approximately 26 percent of the total variance in athlete scores and 18 percent of the total variance in actual competition rankings that are unexplained. It is theorised this unexplained variance is due to a number of important variables associated with the aerial acrobatic routines performed in half-pipe snowboarding that can only ever be assessed with human subjective perception. These variables include the style and execution associated with each aerial acrobatic manoeuvre, the sequence and combination of aerial acrobatic manoeuvres, the amount of risk in the routine, the overall use of the half-pipe including the line taken through the course and how the run progresses and flows. The fact that we could not explain one hundred percent of the shared variance associated with athletic performance within this competition using purely objective information should not be considered a weakness of this approach but in fact a strength as the future of the sport may be best guided a judging criteria that incorporates both objective and subjected criteria.

### 4.4 Sociological Impact

The proposed introduction of a competition judging system or even a performance assessment system for coaches based solely or partially upon objective information into
half-pipe snowboarding (a sport habitually focused on athletic individuality, freedom of expression and long exuding an antiauthoritarian ideology) will no doubt provide sport scientists (as implementers) and the ‘practice community’ (those affected) with challenges. Defining who should determine the future of a sporting discipline ought not be a difficult issue and as such this thesis was a result of action based research involving a close and progressive partnership ideology with the snowboard ‘practice community’. It has thereby allowed elite snowboarders, coaches and competition judges a rigorous and influential forum to describe their perceptions of the potential impact technological change such as the automated performance assessment solution proposed by this study could have within their sporting discipline (Table 21 and 22).

4.4.1 Perceived Importance Of Air Time And Degree Of Rotation

There is a strong ‘practice community’ perception that air-time and degree of rotation play a major role in half-pipe snowboard competition success however these variables are currently assessed by purely subjective measures. There was dominant ‘practice community’ perception on the importance of air-time (and its relationship to amplitude) on competition outcomes. For example, thirteen out of sixteen elite competition judges perceived air-time an important criterion in competition performance assessment, even though it is assessed subjectively. The most important air-time variable (mentioned by eight out of these thirteen subjects) was average air-time (AAT) as it provides an indication of consistency over complete competition runs. As noted by respondents numbered 3 and 10 respectively, the importance of air-time is recognised by both elite-level judging panels and the snowboard ‘practice community’ in general.

... Air-time is considered for every trick from a judging perspective...

... Athletes, coaches, judges, even my own mother agree that the amplitude [associated] with a trick is important...

Although air-time and its relationship with amplitude constituted strong community perception, the perception on the importance of degree of rotation toward competition outcomes was not positive. Although there is a strong ‘practice community’ perception of the importance of degree of rotation in competition performance there is mixed reaction to this component of the sport. The ‘spin to win approach’ is a ‘practice community’ concept that denotes the increasing amount of importance aerial acrobatic degree of rotation is showing in competition results. This competitive approach, where
athletes often increase the number of rotations during each aerial acrobatic manoeuvre, is not wholly endorsed by all of the ‘practice community’. It is perceived to remove the valued components of air-time, amplitude, style and execution in an attempt to increase the degree of rotation. In the study focussed on the perception of elite-level judges to the integration of automated objectivity into competition judging protocols, all stated promoting objective information on degree of rotation within competitions could negatively impact the sport’s future directions. Focusing on degree of rotation was largely perceived to promote a ‘spin to win’ approach to competition; an approach strongly opposed by elite-level judges as noted by the following comment from respondent number 13.

... As for rotation, it seems to have played an increasing role in separating rider’s scores over the years but I feel this has sometimes been in error. Not everybody agrees with the “spin to win” approach. More [rotations] is not necessarily better. Of course having said that, a rider who does large degree rotations must be rewarded, provided they have been executed well...

4.4.2 The Subjective Performance Assessment Paradox

Although the experienced snowboard community are trained to recognise air time and rotational aerial acrobatic complexity, automatically quantified information pertaining to these variables has the potential to assist both coaches and competition judges assess performance for a number of sociological reasons. The first is that there is a paradoxical community perception that the “subjective perception of style and overall run execution” (the current basis for half-pipe snowboarding performance assessment) is considered both a judging strength and a judging weakness. The second is has been termed the sport’s ‘self-annihilating teleology’ and is described in section 1.8. Of the axial codes established in the study focussed on coaches and athlete perception to the concept of automated objectivity promoted within this thesis, the most prominent was, “weaknesses of the current subjective judging system”. The most prevalent sub-dimension related to this axial code was labelled, “subjective perception of style and overall run execution”. The inability of the current subjective judging system to consistently identify correct competition results was a strong perception of the ‘practice community’, as evidenced by this comment from an elite-level snowboard coach.
... It’s subjective, it’s personal opinion. You might think it [a run] looks good, I might think it doesn’t, and that at the moment is the weakness because that’s the difference between who wins and who doesn’t win sometimes. It’s not the fairest way ...

The axial code labelled “strengths of the current subjective judging system” was however, the second most prominent dimension. Paradoxically, the most prevalent sub-dimension associated with this axial code was also labelled, “subjective perception of style and overall run execution”. All subjects mentioned this strength. The second most prevalent perception related with strengths of the current judging system was that it, “allows athletic freedom of expression” as supported by this comment.

... It lets the riders show who they are and what they can do freely. They can basically show their personal being in their style and who they are as a snowboarder. You can go at it, you can invent new tricks, and you can invent new grabs, go big, go small, and spin as fast you want. The system currently lets you do that ...

That fact that paradoxically, the same sub-dimension is considered both a judging strength and a weakness offers insight into half-pipe snowboarding’s’ underlying cultural ethos. All subjects revealed aspects of the sport they valued without posed questioning from researchers. The information emerged into a major theme labelled, “Future direction of the sport”. Snowboard competition seems focused on “freedom of expression and athletic individuality culminating in well executed and stylish performances”. One of the most poignant comments from this study related to the perception of coaches and athletes to the underlying ideology possessed by their sporting discipline was

... It’s a free sport driven by free people ...

4.4.3 The Sport’s Self-Annihilating Teleology

Snowboarding culture appears athlete focused and elite judging protocols have taken into account criteria that athletes value. It is largely unknown however if competitive half-pipe snowboarding can indefinitely maintain a purely subjective style of performance assessment in an era when there are calls for more objectivity in judging Olympic sports. Recent opinion has called for a system of judging to be introduced that is based upon more accurate, reliable and stringent measures, without stifling athletic freedom of expression. As performance levels increase the judging criteria may have to
adapt. Two subjects from the sample of elite-level coaches and athletes revealed this possibility without posed questioning:

... the weakness now is that the sport has progressed at such a rapid rate, the majority of riders are doing the same tricks... up until 2006 it [subjective judging] worked because the level of the sport hasn’t got to a level where it’s an issue yet. Looking forward it is going to be an issue. It’s going to be hard to judge overall impression in the next Winter Olympics, and then it is going to be even harder another 10 years down the track ...

In addition to these external influences, internal forces also need to be considered. Miah (2000) evokes sport’s overall self-annihilating teleology; that increased numbers of athletes ultimately achieve ‘optimal performance’, thereby outgrowing the structure of the game or competition and impinging on the capacity of current judging criteria to reliably assess performance. Sports are then forced to adopt altered performance assessment, equipment changes, or altered game rulings to again separate similarly capable athletes. It was theorised by this study that elite half-pipe snowboarding is not immune to this teleology. There was a dominant perception from the elite competition judges sample (revealed by ten out of sixteen judges) and as noted by respondent number 9, that an underlying self-annihilating teleology could exist within competitive half-pipe snowboarding competition.

... It would be naive to think that a sport such as snowboarding will never get to a point where very little separates elite level athletes. The separation between riders we have clearly seen in the past will one day no longer be discernable by the human eye alone and at which point we will require the continued assistance that technology provides ...

Whilst a majority of the community sampled believed this theoretical phenomenon could exist within half-pipe snowboarding competition, most perceived it as a distant threat. The most prevalent sub-dimension, as noted by respondents numbered 11 and 16 respectively from the elite-level competition judges sample, related to snowboarding’s self-annihilating teleology was labelled, “a distant threat to judging reliability”.

... I do not think snowboarding is there yet ...

... I believe that most [of the community] understand we are a long way from [suffering the effects of] a self annihilating teleology ...
Interestingly however, two subjects revealed this teleology to be a “currently occurring phenomenon”. As noted by respondent number 14 from the elite-level competition judges sample, whilst the effects of increasing numbers of athletes achieving optimal or similarly high levels of performance are currently being experienced in elite-level competition, it is actually having a positive effect on judging reliability.

... This is happening to a degree, but in the case of snowboarding it is making the sport easier to judge by making runs more comparable. We are still a long way from the time where every rider will be performing the same run but as the runs get more and more similar it is possible for the judges to look more at execution and less at difficulty ...

Three elite-level judges perceived the existence of an ‘underlying self-annihilating teleology’ and the subsequent hypothesised affect on current judging reliability a “theory without any relevance in snowboarding” (three did not respond to the question). As noted by respondents numbered 11 and 15 respectively, judging criteria focused on “subjective perception of style and overall run execution” retains what is valued by the ‘practice community’ and will perpetually allow for reliable performance assessment.

... I am not sure how well the [self-annihilating teleology] theory will apply to snowboarding. Judging when all the top riders are doing the hardest tricks and executing them well is exactly what it means to judge elite-level competitions. In fact, there are usually only a handful that has both the hard tricks and good execution. It's not so much about what they're doing as how they're doing it ...

... I do not agree [with the concept of a self-annihilating teleology]. In the case of snowboarding the same trick, even the exact same run can be executed in a different way. Unless snowboarding judges start to dictate a certain perfect execution (like gymnastics) there will still be plenty of room to ride differently and to judge those differences in execution ...

Whilst this thesis has established the effect of sport specific key performance indicators (such as average air time and average degree of rotation) on athlete’s competition scores, it also suggests that accurate and reliable quantification of these sport specific variables may prove beneficial in enhancing subjective judging protocols currently used in elite half-pipe snowboard competition. Subsequently, this thesis has proposed that a MEMS based feedback system could assist judges by providing accurate, electronic ‘memory boards’ (a record of an athlete’s run characteristics currently written by hand)
by quantifying and displaying objective information on sport specific key performance indicators (information currently unavailable to elite-level judges). Theoretically this would enable judges to focus solely on the style, execution and overall composition of aerial acrobatics incorporated into a half-pipe snowboarding competition run. Furthermore, the introduction of such a concept would remove the two most prevalent sociological issues established by this study, that the current subjective perception of style and overall run execution has been paradoxically deemed by the snowboarding community as both a judging strength and a judging weakness and additionally, the use of automated objective information by competition judges would theoretically prevent the issue of half-pipe snowboarding suffering the effects of a self-annihilating teleology.

4.4.4 Perceptions Of An Innovative Performance Assessment Solution

The notion that the system of automated objectivity proposed by this thesis could judge half-pipe competition automatically, without input from subjective judges was however, vigorously opposed by all subjects in the coaches and athletes sample as evidenced by this comment by respondent number 2.

... I think there’s no way it could take over the judging, style and execution is such a big part of the sport ...

Competition judging or performance assessment based purely on objective information opposes what is valued by the snowboarding community, removing the two prevailing judging strengths (that judging is focused on subjective perception of style and run execution and that it allows athletic freedom of expression) and furthermore regiment the competition, as evidenced by this comment from respondent number 5 from the athlete and coaches sample.

... I think that would spoil snowboarding ...

However, the integration of objective feedback with current subjective protocols was perceived positively by all subjects from the coaches and athletes sample. The integration of technological advances without the removal of opportunities for athletic freedom of expression will maintain what the ‘practice community’ values. The dominant perception from a wider international community of elite-level judges was essentially no different, however, competition judges were largely (albeit cautiously) in favour of trialling automated objectivity as a judging aid only and vigorously opposed
its use in determining judging criteria or automatic generation of scores. Adherence to this demand by implementers (sport scientists, engineers, and the sports ruling bodies) would address concern that integration of automated objectivity could remove what is valued by the community and as noted by respondent number 9 in the elite competition judges sample, the opportunity for athletes to control the delivery of their performance and freely express their snowboarding ability.

... We must always keep one thing in mind, that is to never remove the snowboarder’s ability to display their creativity when riding and we must always provide riders the opportunity to dynamically change and be in control of the delivery of their performance ...

The respondents from the elite competition judges sample evidenced a very strong ‘practice community’ perception of what it means to be a snowboarder and the value of retaining the freedom and individuality that the sport entails (all sixteen judges mentioned some aspect of the underlying ideology associated with the sport). Proposing the integration of automated objectivity into an area of the sport (elite-level judging criteria) with the capacity to alter future directions understandably seems in conflict with the sport’s underlying cultural ethos. Unsurprisingly, automated objectivity was not a term used to highlight the sport’s cultural ethos and as noted by respondent number 5, opposition to integration of automated objectivity into snowboarding could potentially be quite vigorous.

... This would be the death of half-pipe snowboard competition ...

In spite of opposition to automated objectivity expressed by a small number of subjects there was dominant ‘practice community’ perception on the importance of air-time (and relationship to amplitude) on competition outcomes. Thirteen out of sixteen judges perceived air-time an important criterion in competition performance assessment, even though it is assessed subjectively (as amplitude) and were largely in favour of using automated objective information on air-time in some form whilst judging. The most prevalent air-time variable (mentioned by eight out of these thirteen subjects) was average air-time (AAT) and although all elite competition judges sampled stated promoting objective information on degree of rotation within competitions could negatively impact the sport’s future directions, they expressed an interest in automated and objective information related to other parameters associated with acrobatic rotation including: 1. The smoothness (consistent rotational velocity) of each rotation. 2. The
exact degree of rotation (the amount of rotation completed during the air-time phase with objective reference to the amount of rotation reverted or completed after the landing).

Unsurprisingly and as noted by respondent number 15 from the FIS World Cup judges sample, the strongest ‘practice community’ perception was to allow ‘subjective perception of execution and run composition’ the most impact on athletic performance assessment. All judges mentioned that any performance assessment method utilised should still contain subjective perception. Judges were largely in favour of allowing subjective perception to contribute at least 50 percent of total competition run score in the hypothetical amalgamation of automated objectivity and traditional subjective measures posed by this thesis. This would maintain the ability of judges to deduct points from snowboarders that achieve large air time and degree of rotation during a specific aerial acrobatic manoeuvre however fail to do so with sufficient style or execution, as noted by this comment by respondent number 4 from the elite competition judges sample.

... A trick with high airtime and difficult rotation that is well executed with great style will usually score high. But if a rider is unstable and showing poor execution, not even lots of air time and [degree of] rotation will get him or her a high score ... 

Six out of sixteen judges sampled (the dominant perception) would use a weighted combination of average air-time, average degree of rotation and subjective perception (25, 20 and 55 percent respectively) to award performance in the proposed hypothetical judging system. Judges however vigorously and unanimously stated they would rather use objective information only as a judging aid. This may therefore be the potential niche for automated objectivity, utilised as a judging aid and as an automated memory board in elite competition. There was dominant community perception that although judges are trained to identify aerial acrobatics and subjectively assess amplitude, a system of automated objectivity could potentially aid performance assessment. As noted by respondent number 9, using automated objectivity in this manner could assist judging without negatively impinging on ‘practice community’ future directions or the sports underlying cultural ethos.
... I see great potential for continued advancement and implementation of technology into snowboard competition to produce more accurate outcomes [however]; only if the athlete's ability to perform in an independent and creative [manner] is not compromised ...

4.4.5 The Future Challenge For Half-Pipe Snowboarding

These studies demonstrated there needs to be a balance between scientific advancement and ‘practice community’ expectations. Elite-level judges, coaches and athletes are largely in favour of trialling automated objectivity as a judging aid and would like to see development of automated competition memory boards. There is however strong opposition of using automated objectivity to determine any component of competition scores or judging criteria. This may be related to the vested interest of the population of elite competition judges sampled. As judges they may feel their future career will be compromised if they can be replaced by an automated system of assessment. This may also be related to vested interest in maintaining snowboarding’s cultural ethos and what is valued within the sport by the ‘practice community’. Judges were not however totally opposed to the idea nor were they opposed to greater consultation within the snowboarding community. There was however strong perception from all coaches, athletes and competition judges that further development and integration of this concept be conducted in close association with core community members and be controlled from within the sport. This is the challenge for elite half-pipe snowboarding competition in the future. While technological advancements are proposed to enhance athletic performance assessment and competition judging protocols, the integration needs to be balanced with the culture of the sport so that ‘practice community’ continue to see themselves as snowboarders, with all the freedom and individuality that entails.

... we do not want to be ballerinas; we want to be snowboarders ...

4.4.6 Future Research

The key considerations for a system of an objective, augmented feedback system based on micro or other technologies to effectively provide specific performance data for the sport of half-pipe snowboarding include: 1. The specificity and relevance of the information to the sport itself. 2. The ability to provide data without hindrance to an athlete’s performance. 3. The accuracy and reliability of the data provided. 4. The processing time required and 5. The accessibility of the method to the wider
snowboarding community including coaches, athletes, judges and team support staff. In this context future research associated with the ideas promoted within this thesis should include: 1. An ongoing analysis of the evolution of key performance indicators and their relationships to subjectively judged competition scores at the elite level. 2. A refinement of the signal processing techniques used to calculate air time and degree of rotation, in particular a refinement of the accuracy and reliability associated with automatic air time calculation and further work on the signal processing of rate gyroscope data to calculate exact degree of rotation, direction of travel, direction of rotation and presence of inversion in aerial acrobatics. 3. A focus on advanced packaging of inertial sensors so that monitoring can be conducted with even less hindrance to an athlete’s performance and focus (for example, packaged inertial sensors should be small and light enough to be imbedded into competition bibs or snowboard jackets, which every athlete has to wear). 4. On board signal processing (removing the limitation of transmitting large amounts of raw inertial sensor data to a computer) and wireless transmission of this on-board processed key performance indicator data to competition judges, performance assessment screens (such as IPAQ’s, I-Phones) and competition scoreboards. 5. A more thorough investigation into the potential sociological impact of the concepts promoted within this study. 6. A thorough validation of the promoted performance feedback system at elite-level snowboarding events.

5 CONCLUSION

This dissertation was focussed on the manner in which objective information is collected and utilised to enhance athletic performance and improve the assessment of that performance in the sport of half-pipe snowboarding. Ultimately introducing a performance assessment concept that although derived from principles currently used in more traditional sporting disciplines, was tailored specifically for elite-level half-pipe snowboarding. In conjunction with both national and international snowboard communities, this dissertation was ultimately designed to accomplish the following goals:

1. Establish the existence of and quantify the relationship between relevant, objective key performance indicators (KPI’s) and subjectively judged scores in elite half-pipe snowboarding competition.
2. Customise, trial and validate wearable micro-technology to automatically quantify objective information related to these sports-specific key performance indicators.

3. Integrate this automated performance assessment concept into elite-level half-pipe snowboarding competition in collaboration with the Australian snowboard community.

4. Assess the community perception and potential sociological impact of this and future integration and allow snowboarding to set an example of how such process can be executed successfully within Olympic sporting cultures.

This thesis has objectively established that average air-time (AAT) and average degree of rotation (ADR) are the two most important key performance indicators in elite-level half-pipe snowboarding competition. This finding is novel, relevant to the sport and if provided in a timely manner, has applications in training and competition performance assessment. Wearable sensor technology suitable for use in routine training and competition environments was therefore customized providing an automated system capable of quantifying air time and degree of rotation. Subsequent integration of this concept into elite half-pipe snowboarding was accomplished with a concept competition, the 2007 Australian Institute of Sport (AIS) Micro-Tech Pipe Challenge. During this competition it was established that by using nothing more than objective information generated by technology and a prediction equation based on previously established weightings, it is possible to account for 74% of the variance subjective competition scores and 82% of the variance in subjective competition rankings, established by an elite level judge. As far as we can ascertain, this was one of the first half-pipe snowboarding competitions in the world to use automated objective information to award performance. For the most part, athletes, coaches and judges are not opposed to utilising the concept of automated objectivity promoted by this thesis, provided it continues to allow athletic freedom of expression and the capacity for athletes to showcase individual style and flair in competition. There is however a very strong perception that further development and integration be conducted in close association with core community members and be controlled from within the sport.

Art, science, technology and innovative thinking will be required to produce the elite athletes of the future and moreover ensure their competition performances are assessed reliably without bias or corruption. For elite half-pipe snowboarding, the current
advancements in micro and other technologies possess the capacity to measure relevant performance information without hindrance to an athlete’s normal movement or focus. This thesis therefore recommends that an automated feedback system based on wearable Micro-Electrochemical System (MEMS) sensors such as tri-axial accelerometers and tri-axial rate gyroscopes be tailored for half-pipe snowboarding and utilised to assist coaches, athletes and competition judges assess performance by providing electronic ‘memory boards’ (a record of an athlete’s run characteristics). This will enable accurate and reliable data to be compiled on the two most important aspects of half-pipe snowboarding whilst allowing subjective assessments of athletic ability to focus solely and more thoroughly on the stylistic facets of performance. Until relatively recently scientists, coaches, athletes, and competition judges wishing to integrate some form of objectivity into half-pipe snowboarding training or competition would be restricted to the use of video based analysis. This thesis reveals it is no longer a question of whether the innovation is there to provide accurate and reliable objective information in an automatic manner, but rather if and how coaches, athletes and competition judges plan to integrate and utilise the information provided.

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PEER REVIEWED PUBLICATIONS

(LIST)


PEER REVIEWED PUBLICATIONS (ABSTRACTS)


ABSTRACT: Half-pipe snowboarding performance is currently assessed by subjective measures. Knowledge of the relative importance of sport specific, objective performance variables however can improve training and competition performance assessment. We analysed objective key performance variables at the Burton Open Australian Half-Pipe Championships over three years (2006, 2007 and 2008). We utilised linear regression to determine the two individual key performance variables most strongly correlated to competition scores and multiple linear regression (enter method) to determine the amount of shared variance in scores explained by these objective variables. The two objective performance variables most highly correlated with competition performance were average air time (AAT) and average degree of rotation (ADR). AAT and ADR are always strongly and positively associated with subjectively judged outcomes and together explain 71 – 94% of the shared variance in competition scores. We compared the magnitudes of differences in AAT and ADR between athletes achieving top three (podium) finishes and those achieving results outside the top three. Magnitude of difference between athletic performances was established with a standardised (Cohens) effect size (ES) with 95% confidence limits. Differences in AAT and ADR between athletes achieving top three podium finishes and those finishing outside the top three routinely showed moderate (ES = 0.6 – 1.2 95% CL) to very large (ES > 2.0 95% CL) effects. Knowledge of these key performance variables and their importance at the elite-level can be used to improve training and competition performance assessment protocols.


ABSTRACT: This paper provides a review of objective performance assessment in elite half-pipe snowboarding. Half-pipe snowboarding is currently coached and judged in competition using subjective measures. Like other sports that rely on subjectivity
however, the methodology underpinning how coaches assess athletic progression and judges score performance is open for debate. This paper focuses on technology assisted, objective performance assessment. Key considerations are the specificity of the information, the accuracy and reliability of results, the processing time required and the current accessibility.


ABSTRACT: The authors have previously reported a strong relationship between video based objective data (air-time and degree of rotation) and subjectively judged scores awarded during elite half-pipe snowboard competition. Advancements in sports monitoring technologies now provide the capacity to accurately and automatically quantify this objective information. This may assist current subjective coaching and competition judging protocols provided the integration process imparts a large element of control to key players within the sport. The authors therefore recently hosted an invitational half-pipe snowboard competition (2007 Australian Institute of Sport (AIS) Micro-Tech Pipe Challenge) designed to evaluate whether the snowboard community would embrace a competition where results were in part determined by automated objectivity, explore the practical, logistical and technical challenges associated with conducting such an event and evaluate the relationship between subjective judging and results predicted from objective information to see if prior research had ecological validity. Ten elite male half-pipe snowboarders were instrumented with inertial sensors throughout this competition. A prediction equation using previously established weightings of average air-time and average degree of rotation accounted for 74% of the shared variance in subjectively judged scores awarded during this competition. Although our predictions of overall scores and rankings were good there was still 26% of the total variance unexplained. This should not be considered a weakness of this approach but a strength as the subjective components of style and execution should never be removed from the sport. The future of half-pipe snowboarding however may be best guided a judging protocol that incorporates both objective and subjective criteria.

ABSTRACT: This interview was focussed upon gaining ‘practice community’ insight into the potential of micro-technology and subsequent automated objectivity to assist coaches and competition judges with performance assessment during elite half-pipe snowboarding. The sport of half-pipe snowboarding has however traditionally assessed performance during training, free riding and competition by purely subjective measures and until recently has had very little to do with sport science and the focus of objectifying performance parameters associated with rigorous scientific inquiry. The authors have previously shown there is a strong relationship between objective key performance variables such as air-time and degree of rotation (assessed using video based analysis) and an athletes’ subjectively judged score during elite half-pipe snowboarding competitions. Video based analysis however requires labour intensive manual post processing of data and is associated with a large time delay in information feedback. As such it is theorised to have limited potential for the feedback of objective information to snowboard athletes, coaches, and judges. The authors have therefore worked alongside numerous collaborators from the Australian Institute of Sport (AIS), the Olympic Winter Institute of Australia (OWIA), Griffith University (GU) and Catapult Innovations to develop a system of automated objectivity based on tri-axial accelerometers and tri-axial rate gyroscopes that can calculate air-time and degree of rotation during half-pipe snowboard runs. The concept was originally focussed on enhancing current training protocols but has also shown potential to support judges in assessing athletic performance during elite half-pipe snowboard competition. Although there is a potential benefit to using systems of automated objectivity within the sport of snowboarding there are also potential drawbacks associated with objectifying a sport that prides itself on providing a platform that allows freedom of expression and the capacity to showcase athletic individuality. It is believed that the integration of any form of objectivity into a sport such as half-pipe snowboarding should be conducted whilst allowing key ‘practice community’ members control over the overall direction. This 45-minute interview was conducted by Jason Harding (AIS sport scientist) with Ben Wordsworth (the Australian national snowboard coach currently affiliated with the Olympic Winter Institute of Australia) in between surfs at Manly Beach NSW Australia on Wednesday 1st October 2008.
ABSTRACT: We have previously presented data indicating that the two most important objective performance variables in elite half-pipe snowboarding competition are air-time and degree of rotation. Furthermore, we have documented that air-time can be accurately quantified by signal processing of tri-axial accelerometer data obtained from body mounted inertial sensors. This paper adds to our initial findings by describing how body mounted inertial sensors (specifically tri-axial rate gyroscopes) and basic signal processing can be used to automatically classify aerial acrobatic manoeuvres into four rotational groups (180, 360, 540 or 720 degree rotations). Classification of aerial acrobatics is achieved using integration by summation. Angular velocity ($\omega_{i, j, k}$) quantified by tri-axial rate gyroscopes was integrated over time ($t = 0.01s$) to provide angular displacements ($\theta_{i, j, k}$) at ith sample points. Absolute angular displacements for each orthogonal axes ($i, j, k$) were then accumulated over the duration of an aerial acrobatic manoeuvre to provide the total angular displacement achieved in each axis over that time period. The total angular displacements associated with each orthogonal axes were then summed to calculate a composite rotational parameter called Air Angle (AA). We observed a statistically significant difference between AA across four half-pipe snowboarding acrobatic groups which involved increasing levels of rotational complexity ($P = 0.000, n = 216$). The signal processing technique documented in this paper provides sensitive automatic classification of aerial acrobatics into terminology used by the snowboarding community and subsequently has the potential to allow coaches and judges to focus on the more subjective and stylistic aspects of half-pipe snowboarding during either training or elite-level competition.


ABSTRACT: Automated and objective information specific to half-pipe snowboarding has now been made available with micro-technology and signal processing techniques. In consultation with the ‘practice community’ this has been introduced into training and
competition in Australia. It is understood that any integration of technology into elite sport can effect change beyond the original purpose and can often generate unintended consequences. We have therefore evaluated the perceptions of key members of the elite half-pipe snowboard community in regards to how emerging technology could interface with the sport. Data were collected via semi-structured, open ended interviews with 16 international, elite-level half-pipe snowboard competition judges. This study revealed 8 dimensions and 42 sub-dimensions related to the community’s perceptions to 5 major themes that emerged during interviews. The major themes included: 1. Snowboarding’s Underlying Cultural Ethos 2. Snowboarding’s Underlying Self-Annihiliating Teleology 3. Technological Objectivity 4. Concept Management 5. Coveted Future Directions. There was dominant perception that an underlying self-annihilating teleology could exist within competitive half-pipe snowboarding. This was believed however to pose a distant threat on judging protocols to reliably assess performance. Judges sampled in this study were largely in favour of using automated objectivity to enhance the judging process however, with a number of caveats. Most importantly that objective information is to be used as a judging aid and not for automatic generation of scores. This would address the most prevalent concern that integrating any automated objectivity into snowboarding could potentially remove freedom of expression and the opportunity to showcase athletic individuality - traits valued by the ‘practice community’. Our data highlight that successful implementation of emerging technologies in sport will be not be based on the type of technology developed but instead by the integration process which must feature a large element of control imparted to the key players within the sport.


ABSTRACT: Recent analysis of elite-level half-pipe snowboard competition has revealed a number of sport specific key performance variables (KPV’s) that correlate well to score1. Information on these variables is difficult to acquire and analyse, relying on collection and labour intensive manual post processing of video data. This paper presents the use of inertial sensors as a user-friendly alternative and subsequently implements signal processing routines to ultimately provide automated, sport specific
feedback to coaches and athletes. The author has recently shown that the key performance variables (KPV’s) of total air-time (TAT) and average degree of rotation (ADR) achieved during elite half-pipe snowboarding competition show strong correlation with an athlete’s subjectively judged score1. Utilising Micro-Electrochemical System (MEMS) sensors (tri-axial accelerometers) this paper demonstrates that air-time (AT) achieved during half-pipe snowboarding can be detected and calculated accurately using basic signal processing techniques. Characterisation of the variations in aerial acrobatic manoeuvres and the associated calculation of exact degree of rotation (DR) achieved is a likely extension of this research. The technique developed used a two-pass method to detect locations of half-pipe snowboard runs using power density in the frequency domain and subsequently utilises a threshold based search algorithm in the time domain to calculate air-times associated with individual aerial acrobatic manoeuvres. This technique correctly identified the air-times of 100 percent of aerial acrobatic manoeuvres within each half-pipe snowboarding run (n = 92 aerial acrobatic manoeuvres from 4 subjects) and displayed a very strong12 correlation with a video based reference standard for air-time calculation (r = 0.78 ± 0.08; p value < 0.0001; SEE = 0.08 ×/÷ 1.16; mean bias = -0.03 ± 0.02s) (value ± or ×/÷ 95% CL).


ABSTRACT: No scientific research has yet targeted the athletic performance aspects or subjective judging protocols associated with elite half-pipe snowboard competition. Recently however, sport scientists from the Australian Institute of Sport (AIS) initiated a video based analysis of key performance variables (KPVs) associated with elite half-pipe snowboard competition. The development of a preliminary automated feedback system based upon Micro-electrochemical Systems (MEMS) sensors such as tri-axial accelerometers and tri-axial rate gyroscopes, designed to calculate objective information on these sport specific KPVs was initiated in parallel. Although preliminary, the results may provide practical benefit for elite half-pipe snowboard training and current subjective judging protocols. In light of theorised implications, this paper investigated the perception and possible social impact of these concepts on the ‘practice community’. Data was collected via semi-structured, open ended interviews with nine
subjects (six athletes, two coaches, and one judge) currently involved in elite half-pipe snowboard competition. This study revealed 6 dimensions and 20 sub-dimensions relating to the ‘practice community’’s perceptions of 3 major themes that emerged during interviews. The themes included: 1) State of the current subjective judging system, 2) Automated feedback and objective judging system, and 3) Future direction of the sport. There was dominant negative perception of a proposed automated judging concept based solely on objective information unless the system integrates with the current subjective judging protocol and continues to allow athletic freedom of expression and the capacity for athletes to showcase individual style and flair in elite competition. The results of this study provide the ‘practice community’ an initial public forum to describe its perceptions to future automated judging concepts, nominating them to be the primary determinants of change, technological or otherwise, within their sporting discipline.
INTERNATIONAL CONFERENCE PRESENTATIONS


NATIONAL CONFERENCE PRESENTATIONS


ACADEMIC AWARDS


MEDIA

5. Australian Institute of Sport – 16th December 2008 – ‘High-tech leap for snowboarding’
6. Gold Coast Bulletin – 9th August 2008 – ‘Sporting Glory – Griffith students find innovative ways to be part of the action – Enter the Sporting Arena’
7. Smart Start Magazine 15th October 2008 – ‘Make your own wave – Sealed Section’
8. The Courier Mail – 7th September 2007 – ‘Electronic memory board to give athletes the edge’
10. Australian Broadcasting Corporation, ABC South East NSW - 2nd August 2007 – ‘Giving our athletes the winning edge’
11. Canberra Times – 1st August 2007 – ‘Technology helps carve a competitive edge’
12. The Sydney Morning Herald – 31st July 2007 – ‘A measured approach to the air up there’