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Muscle activity analysis with a smart compression garment

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Abstract

Analysis of muscle exertion while exercising gives insight into an individual's balance, technique and activity performance. Smart Compression Garments (SCG) function as a low-cost material pressure mapping system integrated within consumer compression apparel capable of assessing both muscle use, and limb positioning. The SCG used for testing contained 5 sensors capable of measuring pressure between fabric and skin above key muscle groups of the lower limbs with marker-based video analysis to determine Knee Flexion Angle. The SCG was calibrated through voluntary contractions of target muscles, where surface pressure range and EMG data allowed for the quantification of exertion levels whilst the participant performed leg extension and flexion activities. Each sensor measured a viable range of pressure relative to the exertion level for each muscle group with a strong repeatable nature and correlation to muscle activation load. Additionally, analysis of the muscle loading variation of the quadriceps and hamstrings whilst walking on a treadmill at low speed was shown to match pre-established gait activation behaviour. Results support that a SCG with low-cost integration of piezoresistive materials has considerable promise in determination of muscle loads and potential injury conditions for the purpose of athlete training support.

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Keywords: Smart Compression; Pressure; Muscle Force; EMG; Garment

1. Introduction

Unlike many other medical injuries, almost 50% of all sports-related injuries are preventable [1]. The risk of injury and the associated complications reduce the participation and performance across all levels of sport. The muscles and joints of the lower limbs (i.e. Hamstrings, Cruciate Ligaments) are particularly susceptible to

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overload/strain injuries during sporting activities. At a recent conference presentation to leading participants within the Australian sports technology industry, Doctor Peter Larkins, arguably the Australian Football League's (AFL) most prominent medical consultant highlighted the impending need to solve the major medical problems experienced within elite sport [2]. He placed significant importance on the need to address the ever increasing rate of lower leg musculoskeletal injuries sustained by players at all levels of the code, a statistic that continues to grow each year despite the high financial investments to counteract this trend [3]. It has become apparent that current injury mitigation techniques, employed medical staff and clinical tests are failing to stem the rising injury rate within the elite sporting code. There is an important need to provide a novel and improved solution, not one just for the elite, but also for the sub-elite who are active at least once per week in sporting activities (11.7 million in Australia alone [4]). These participants do not have direct access (both logistically and financially) to the equivalent level of support seen in such developed codes as the AFL, participants whom both during and after their participation sustain a higher percentage of musculoskeletal sporting injuries. This research paper continues the preliminary work in the development of a solution to these problems through a Smart Compression Garment (SCG), a wearable system that directly monitors the pressure response experienced on a compression garment during both muscular and skeletal limb activity [5]. This is capable through the direct development and integration of a low-cost pressure mapping system into a physical garment. Recognition of gross muscular activity is achieved for exercise analysis through the measurement of muscular surface pressures and limb positioning as a means to mitigate injury potential through uneven or overload straining of the activated (or non-activated) muscles. The foreseen benefits realised from research into a SCG stretch beyond the domain of professional sport, to encompass multidisciplinary enrichments to healthcare and rehabilitation sectors.

2. Materials and Methodology

2.1. The Smart Compression Garment

A previously developed SCG prototype by the research team [5] was utilised for its capability of mapping pressure changes over key target muscle groups in the right leg of a wearer. Five of the integrated material pressure sensors were utilised for the test measurements, where each sensors was constructed in-house from a piezoresistive polymer (Rmat2a, RMIT material code), with an individual sensing area of $4cm^2$. Calibration of the sensors was accurately determined ($R^2 > 0.97$) through the correlation of changes in electrical conductance to an applied mechanical load, as measured by a commercial force transducer (Kistler 9317B sensor, Kistler Switzerland).

Skins A400 long tights, an off-the-shelf consumer compression garment, was utilised as the core garment with the sensor placement positioned above the quadriceps (Rectus Femoris, Vastus Lateralis, Vastus Medialis), and hamstrings (Biceps Femoris, Semitendinosus) muscle groups. Measurement of the knee flexion angle (θ_{KFA}) was achieved through the use of marker-based video analysis using the Kinovea visual tracking software (Kinovea.org) and a video camera (GoPro Hero4 Silver, 120fps, 720p, corrected for lens distortion). An electronics module positioned in the waistband provided data collection of the system. The module consisted of a lithium-polymer battery, microcontroller (Teensy 3.1, PJRC.com) with the necessary voltage divider circuits, and a Bluetooth unit for wireless tethering to a computer where data visualisation and logging were performed.

2.2. Estimation of Muscle Force

By selecting an activity where the desired behaviour of the motion is known, an *inverse-dynamic* approach was utilised to determine the forces involved, as such the muscle force in the quadriceps and hamstrings could be estimated with reliable accuracy. This allows correlation of the corresponding muscle force to that of the pressure variation experienced above the skin at the muscle surface as measured by the SCG. As pressure mapping of the muscles relies upon pressure measurements to infer resultant motion, it functions as a *forward-dynamic* system, so to assist in validation of results Electromyography (EMG), another forward-dynamic system, was incorporated into the testing methodology.