



**COMPARISON OF MUSCLE OXYGENATION AND TOTAL
HEMOGLOBIN LEVELS DURING ISOKINETIC CONCENTRIC AND
ECCENTRIC CONTRACTION AT DIFFERENT SPEEDS IN ATHLETES**

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ABSTRACT

The aim of this study is to investigate potential differences in muscle oxygen saturation (SmO_2) and total hemoglobin level (tHb) within the vastus lateralis (VL) and biceps femoris (BF) muscles, between sedentary individuals and athletes during isokinetic maximal concentric (CON) and eccentric (ECC) contractions executed at 60, 180, 300°/sec speeds. The study included 17 male volleyball athletes with a mean age of 17.53 ± 1.50 years and 14 healthy sedentary individuals with a mean age of 18.21 ± 1.57 years. Body composition was assessed by body analysis scale, and adipose tissue thickness was measured by skinfold caliper. Isokinetic CON and ECC contractions were performed with a Cybex NORM® by Humac CA, USA. Quadriceps contractions were performed in a seated position and hamstring contractions in a prone position. For measuring SmO_2 and tHb Train.Red sensor, was placed on the participant's dominant leg, specifically targeting the VL and BF. According to the results, in the VL CON, SmO_2 , tHb and oxygenated hemoglobin (O_2Hb) levels at a velocity of 300°/sec were significantly ($p < 0.05$) greater compared to those recorded at 60°/sec and 180°/sec, while deoxygenated hemoglobin (HHb) values did not show any differences ($p > 0.05$) among the speeds. In the BF CON, only the hemoglobin difference (Hb Diff) was found to be significantly ($p < 0.05$) greater during 300°/sec compared to 60°/sec. In the VL, Hb Diff, tHb, O_2Hb were higher ($p < 0.05$) in CON than in ECC at 60°/sec., while HHb values did not show any differences. In the BF, Hb Diff and O_2Hb in the ECC were statistically higher than in the CON at 60°/sec ($p < 0.05$). In the VL, volleyball athletes had higher total blood flow measures than sedentary individuals, while no group differences were found in the BF. Our study highlights the benefits of higher velocity exercises in optimizing oxygenation without significant metabolic demands. It also shows that exercise velocities affect muscle oxygenation and blood flow differently in sedentary individuals and athletes, underscoring the need for tailored exercise protocols.

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Key Words: : Near infrared spectroscopy, muscle oxygen saturation, total hemoglobin level, isokinetic, volleyball athletes.

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SPORCULARDA FARKLI HIZLARDA İZOKİNETİK KONSANTRİK VE EKSENTRİK
KASILMA ANINDA KAS OKSİJENASYON VE TOPLAM HEMOGLOBİN DÜZEYLERİNİN
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ÖZET

Amaç

İzokinetik dinamometri kullanılarak, farklı hızlarda ve kasılma türlerinde çeşitli kasların metabolik özellikleri hakkında bilgi edinmek mümkündür. Bu bilgiler, özel rehabilitasyon programlarının tasarlanmasında, yaralanmaların önlenmesine yönelik stratejilerin uygulanmasında ve farklı popülasyonlarda performansı artırmayı amaçlayan etkili kişiselleştirilmiş antrenman rejimlerinde faydalı olabilir.

Öte yandan, Yakın Kızılötesi spektroskopisi (NIRS), farklı egzersiz modalitelerinde lokal kas oksidatif metabolizmasını ölçme özelliği nedeniyle popülerlik kazanmıştır. NIRS, noninvaziv bir optik yöntem olarak kullanılmaktadır. Kas oksijen saturasyonunun (SmO_2) ve toplam hemoglobin (tHb) seviyelerinin sürekli olarak izlenmesini sağlar. SmO_2 , kasların oksijeni nasıl kullandığını ve aldığını değerlendirmeyi, kasta oksijen alımı ve kullanımı arasındaki dengeyi belirlemeyi amaçlarken, tHb ölçümleri küçük kan damarlarının hacmindeki değişiklikleri göstermektedir.

Bu fizyolojik değerlendirmeden yararlanarak antrenman verimliliğini artırmak ve kuvvet gelişimini en üst düzeye çıkarmak mümkündür. Minimum yorgunlukla metabolik stresin büyüklüğüne ve süresine ulaşmak için tasarlanmış özel protokoller hakkında literatüre değerli bilgiler sağlayacaktır. Ayrıca, özellikle ön çapraz bağ rehabilitasyonu bağlamında, antrenman ve toparlanma için gelecekteki önerilerin yolunu açacaktır.

SmO_2 ve tHb seviyelerinin ölçümü önemli olmasına rağmen, bu konuda çok az çalışma vardır. Farklı hızlarda (60, 180, 300°/s) izokinetik kasılma sırasında VL ve biceps femorisin (BF) SmO_2 ve tHb düzeylerine ilişkin literatürde eksiklik bulunmaktadır. Ayrıca, bu parametre ölçümlerinin farklı fiziksel uygunluk seviyelerine sahip bireylerdeki etkilerini araştırmak önemlidir, çünkü farklı bireyler kas kasılma modellerinde farklılıklar gösterebilir ve bu da potansiyel olarak kas grupları arasında SmO_2 ve tHb seviyelerinde farklılıklara neden olabilir. Yakın zamanda yapılan bir çalışma, fiziksel inaktifliğin iskelet kası metabolizması üzerindeki büyük etkisini vurgulamakta ve enerji dengesi korunmadığında yağ birikiminin artmasına ve kas kütlesi kaybına yol açtığını ortaya koymaktadır. Bunun aksine, aerobik egzersiz sporcuların fiziksel işlevlerini iyileştirir ve iskelet kası oksijen

içeriğini artırır. Literatürde, NIRS kullanarak sedanter ve sporcular arasında maksimal diz çevresi kaslarında CON ve ECC kasılmalarını karşılaştıran bir çalışma bulunmamaktadır.

Bu nedenle, bu çalışmanın temel amacı, dominant bacakta VL ve BF kas kuvveti, gücü ve dayanıklılığını ölçerken, 60, 180 ve 300°/s hızlarda maksimal CON ve ECC kasılmaları sırasında SmO₂ ve tHb seviyelerindeki değişiklikleri araştırmaktır. Bu çalışmanın ikincil amacı, sağlıklı sedanter bireyler ve sporcular arasında farklı kasılma türleri (CON ve ECC) ve hızları (60, 180, 300°/s) arasındaki SmO₂ ve tHb yanıtlarını karşılaştırmak ve analiz etmektir.

Bu sayede, bu bilgilerin sadece düzenli antrenman yapan bireyler için değil, sedanter bireyler için de anlaşılabilir olması amaçlanmıştır.

Bu amaçla çalışmamıza yaş ortalaması 17,53±1,50 (yıl); vücut kitle indeksi (VKİ) 22,9±1,7 (kg/m²); yağ yüzdesi; 11,26±4,44 (%); spora başlama yaşı; 10,70±2,59 (yıl) olan 17 lisanslı profesyonel voleybol sporcusu, ve Yaş; 18,21±1,57 (yıl); VKİ; 22,01±2,27 (kg/m²); yağ yüzdesi 16,92±5,75 (%) ve düzenli fiziksel aktivitesi olmayan 14 sağlıklı sedanter birey dahil edilmiştir.

Gereç ve Yöntem

Dahil edilme kriterlerinden, son 1 yıldır düzenli spor yapan lisanslı sporcular ve Uluslararası Fiziksel Aktivite Anketi'ne (IPAQ-kısa form (SF)) göre sedanter olanlar bu çalışmaya dahil edilmiştir. 15-69 yaş arası bireylerde fiziksel aktivite ve sedanter davranışı değerlendirmek için yaygın olarak kullanılan bir öz değerlendirme aracıdır. Katılımcıların fiziksel aktivite düzeyini değerlendirmek için IPAQ-SF-T'nin Türkçe versiyonu kullanılmıştır. Anket 7 sorudan oluşmaktadır. Katılımcılar ne sıklıkla fiziksel aktivitede bulunduklarını bildirmişlerdir. Ardından, orijinal IPAQ-SF puanlama protokolünü izleyerek haftalık toplam metabolik eşdeğer görevlerine göre 3 kategoriye ayrılmışlardır.

İnaktif: Haftada 600 MET dakikadan daha az süre ile,

Minimal düzeyde aktif: Haftada 600 ila 3000 MET-dakika arasında.

Yüksek düzeyde aktif: Haftada 3000 MET-dakikayı aşan.

Fiziksel aktivitesi çok az olan ya da hiç olmayan katılımcılar sedanter grupta kategorize edilmiştir.

Çalışma onayı için 26 Aralık 2023 tarihinde etik kuruldan izin alınmıştır. Çalışmaya başlamadan önce sporculara ve sağlıklı sedanter bireylere çalışmanın içeriği hakkında detaylı bilgi verilmiştir. Katılımcılar ilgili formları okuyup imzalayarak anladıklarını ve kabul ettiklerini teyit etmişlerdir. Değerlendirmeler Gazi Üniversitesi Sağlık Bilimleri Fakültesi Fizyoterapi ve Rehabilitasyon Bölümü Sporcu Sağlığı Birimi'nde gerçekleştirilmiştir.

Çalışmadaki katılımcılara değerlendirmelerden önce bisiklet ergometresi kullanılarak 5 dakikalık bir ısınma seansı uygulanmıştır. Katılımcılara TANITA BC 418 vücut

kompozisyon cihazı kullanılarak segmental vücut analizi yapılmıştır. Toplam vücut ağırlığı, farklı segmentlerdeki yağ kütlesi (sağ ve sol taraflar, üst ve alt ekstremiteler ve gövde), segmental yağ yüzdesi, belirli vücut segmentlerindeki kas kütlesi, VKİ, bel-kalça oranı gibi ölçümler TANITA kullanılarak kaydedilmiştir. Analizler için sadece toplam vücut ağırlığı, vücut yağ yüzdesi ve VKİ ile ilgili veriler analizlere dahil edilmiştir. NIRS cihazını takmadan önce, VL ve BF kasları üzerindeki deri kıvrım kalınlığı bir kumpas (model: 12-1110) kullanılarak ölçülmüştür.

Hem BF hem de VL kasları için ayrı ayrı deri kıvrım kalınlığı iki ölçümün ortalaması alınarak belirlenmiştir. Ölçülen deri kıvrımı kalınlığı ikiye bölünmüştür. Bu bölme işlemi yağ dokusunun kalınlığını hesaplamayı amaçlamıştır. Ölçümler NIRS cihazının bulunduğu yerde bir kumpas kullanılarak gerçekleştirilmiştir. Bu ölçümler, Uluslararası Kinantropometri İlerleme Derneği (ISAK) protokolünde sağlanan yönergelerle bağli kalmıştır. ISAK antropometrik standartlar konusunda global olarak tanınan bir otoritedir.

CON ve ECC, Humac CYBEX Norm İzokinetik sistemi kullanılarak gerçekleştirilmiştir. Değerlendirme iki bölümden oluşmuştur: kuadriseps kaslarının oturur pozisyonda değerlendirilmesi ve hamstring kaslarının yüzüstü pozisyonda değerlendirilmesidir. Test seansı sırasında Train.Red sensörleri, özel olarak tasarlanmış uyarlanabilir bir bant kullanılarak, özellikle VL ve BF'yi hedef alacak şekilde katılımcıların dominant bacağına yerleştirilmiştir. Her iki kas için konumlandırma, Scott Cocking tarafından yürütölen bir Elektromiyografi çalışmasından elde edilen bulgulara göre belirlenmiştir.

Dinamometre kalibrasyonu ürünün kılavuzuna göre ayarlanmıştır. Kuadriseps kasılması sırasında, katılımcılar otururken bir kayış kullanılarak sandalyeye bağlanmıştır. Daha sonra katılımcılara dinamometre sandalyesinin kenarlarını elle kavramaları talimatı verilmiştir. Kompansatuar hareketlerden kaçınmak için pelvis ve toraks sıkıca desteklenmiş ve stabilize edilmiştir. Uyluk üzerine bir kemer yerleştirilmiştir. Kuadriseps-patella tendonunun bağlantı noktasının 3 cm yukarısına yerleştirilmiştir. Ek olarak, dinamometrenin rotasyon eksenini hizalandı. Bu hizalama femoral eklem eksenini ile sağlandı.

Ayak bileğı pedleri pozisyonlandırıldı. Bunlar lateral malleolün yaklaşık iki parmak genişliğinde yukarısına yerleştirildi. Ayrıca, katılımcının konfor seviyesine göre modifiye edilmiştir. Diz hareketinin kapsamı, yani hareket açıklığı belirlenmiştir. CON kasılmaları için 90 derece fleksiyon pozisyonundan 0 derece ekstansiyon pozisyonuna ve ECC kasılmaları için 90°'den 10°'ye ayarlanmıştır. Tüm testlerde, ekstremitenin ağırlığı tarafından uygulanan yerçekimi kuvvetini dengelemek için ' gravity kompanzasyon' fonksiyonu etkinleştirilmiştir.

Kuadriseps kasının VL kısmını hedeflemek için, NIRS sensörü anterior superior iliak spine'den patellanın superior lateral kenarına kadar olan mesafenin üçte ikisine yerleştirilmiştir. Kuadriseps kası farklı hızlarda bir dizi testle değerlendirilmiştir: Başlangıçta, maksimal CON kasılması için yavaş olarak kabul edilen saniyede 60 derece (60°/s) hızda 5 tekrar gerçekleştirilmiştir. Bunu saniyede 180 derecelik (180°/s) orta hızda 10 tekrar ve ardından saniyede 300 derecelik (300°/s) yüksek hızda 15 tekrar yapmıştır. Daha sonra, maksimal ECC kasılması için 60°/s hızda 5 tekrar gerçekleştirilmiştir. Ardından, aynı kas grubu için 60°/s hızda ECC kasılmaları yapılmıştır.

Hamstring kasının izokinetik değerlendirmeleri için dinamometre kalibrasyonu üretici kılavuzuna göre yapılmıştır. Gereksiz kas alımını en aza indirmek ve hareketi diz eklemine odaklamak için pelvis ve diz üzerinde ayarlamalar yapılmıştır. Yüzüstü pozisyonda, pelvis bir kemerle sabitlenerek kalça 180 derece hizalandı. Dinamometrenin rotasyon eksenini femoral eklem eksenine ile hizalanmıştır.

Medial malleolün yaklaşık 3 cm yukarısına, katılımcının ayağını rahatça yerleştirecek şekilde bir ayak bileği pedi yerleştirilmiştir. Hareket aralığı CON kasılmaları için 0° diz ekstansiyonundan (başlangıç pozisyonu) 90° diz fleksiyonuna ve ECC kasılmaları için 90°'den 10°'ye ayarlanmıştır. Gravitasyonel etkileri kompanse etme işlevi etkinleştirilmiştir.

Hamstring kasının BF kısmı için NIRS sensörü, iskiyal tüberositeden lateral patellanın orta noktasına kadar olan orta nokta mesafesine yerleştirilmiştir. Hamstring kasları bir dizi testle değerlendirmeye tabi tutulmuştur. Buna 60°/s'de (düşük hızda) 5 tekrarlı maksimal CON kasılmaları, ardından 180°/s'de (orta hızda) 10 tekrar ve daha sonra 300°/s'de (yüksek hızda) 15 tekrar yapılması dahildir. Ek olarak, 60°/s'de 5 tekrar şeklinde maksimal ECC kasılmaları gerçekleştirilmiştir.

Her hızda değerlendirmeye başlamadan önce katılımcılar üç deneme tekrarı yapmıştır. Bu tekrarlar, kendi algıladıkları eforun %50'sine denk gelen submaksimal yoğunlukta gerçekleştirilmiştir. Bu, katılımcıların prosedüre aşına olmalarını ve etkili bir şekilde ısınmalarını sağlamıştır. Submaksimal denemeler arasındaki aralıklarda 30 saniyelik bir ara verilmiştir. Ayrıca, her test hızı arasında 1 dakikalık bir dinlenme süresi sağlanmıştır. Her değerlendirmeden önce katılımcılara sözlü talimatlar verilmiştir. Bu talimatlar standartlaştırılmış ve maksimal efor sarf edilmesi gerektiği vurgulanmıştır. Katılımcılara bu eforu tüm hareket aralığı boyunca sürdürmeleri talimatı verilmiştir. Kas-iskelet yorgunluğunu azaltmak için iki pozisyon arasında 10 dakikalık bir dinlenme süresi verilmiştir. Her bir izokinetik açısal hız için her bir tekrardaki tepe torku Nm/kg cinsinden kaydedilmiştir.

Bu çalışmada Train.Red FYER NIRS cihazını kullandık. Bu cihaz sürekli dalga NIRS sensörü olarak fonksiyon görmektedir. Bu sensörde 760 nm ve 850 nm olmak üzere iki farklı dalga boyunda ışık yayan bir ışık yayan diyot bulunmaktadır. Ayrıca 35 mm'lik bir orta aralıkta konumlandırılmış 64 pikseli bir çizgi alıcıya sahiptir. Gönderici ve alıcı arasındaki bu mesafe, interpod mesafe diye adlandırılmaktadır. Sonuç olarak, penetrasyon derinliği bu mesafenin yaklaşık yarısı olarak hesaplanmıştır. Bu da toplamda 17,5 mm'ye denk gelmektedir. Bu çalışmaya dahil edilen tüm katılımcıların deri altı yağ kalınlığı NIRS cihazının bulunduğu yerde 17,5 mm'nin altındaydı.

Sensör bir mobil telefon uygulamasına bağlanmıştır. Bu sayede verilerin toplanması ve aktarılması mümkün olmuştur. Veriler 10Hz hızında örneklenmiştir. Cihaz, O_2Hb , HHb , SmO_2 ve tHb 'nin mutlak seviyelerini belirlemek için modifiye Beer-Lambert yasasına göre çalışmıştır.

- O_2Hb : Mikrovaskülatürdeki oksijen kaynağını yansıtan oksijenli bir Hb'dir.
- HHb : Mikrovasküler oksijen ekstraksiyonunu yansıtan deoksijenlenmiş Hb'dir.

- *SmO₂*: Kas oksijen satürasyonu olarak adlandırılır ve kaslara ne kadar oksijen verildiğini ve ne kadarının kullanıldığını değerlendirmek için kullanılır. İskelet kaslarının küçük kan damarları içinde yüzde olarak ölçülür ve $SmO_2 = [(O_2Hb)/(tHb)] * 100$ şeklinde ifade edilir.
- *tHb*: Total Hb konsantrasyonu olarak adlandırılır. Küçük kan damarlarındaki kan hacmindeki değişiklikleri değerlendirmek için kullanılır.
- *Hb Diff*: O₂Hb ve HHb arasındaki farktır.

Sensörü deneklerin uyluğuna sabitlemek için özel bir kayış kullanılmıştır. Kayış gerilebilir kumaştan yapılmıştır, stabiliteyi sağlamak ve bacak üzerinde kaymayı önlemek için dört kaymaz silikon şerit içermektedir.

Bulgular

Sonuçlara göre, elit voleybol sporcuları ile sağlıklı sedanter bireyler arasında yaş ve VKİ açısından fark yoktur ($p > 0.05$). Ancak, elit voleybol sporcuları ile sağlıklı sedanter bireyler karşılaştırıldığında vücut ağırlığı ve boy uzunluğunda istatistiksel olarak anlamlı bir farklılık bulunmuştur ($p < 0.05$). Çalışmamızda, VL kasından yapılan CON ölçümleri, 300°/sn hızdaki *SmO₂* ve *tHb* seviyelerinin, 60°/sn ve 180°/sn'de kaydedilenlere kıyasla önemli ölçüde ($p < 0,05$) daha yüksek olduğunu ortaya koymuştur. Ek olarak, 300°/sn'deki O₂Hb konsantrasyonları daha düşük hızlara göre önemli ölçüde ($p < 0,05$) yükselirken, HHb değerleri hızlar arasında önemli bir farklılık göstermemiştir. Voleybol sporcularının toplam kan akışı ölçümleri sedanter bireylerinkinden daha yüksekti.

BF için, çalışmamızda, Hb Diff'in 300°/sn sırasında 60°/sn'ye kıyasla önemli ölçüde daha yüksek olduğu bulunmuştur ($p = 0.008$) ve *SmO₂*'de genel etki bulunmuştur, ancak sonraki ikili karşılaştırmalar herhangi bir spesifik fark göstermemektedir. Ayrıca, *SmO₂*, *tHb*, O₂Hb ve HHb açısından Hız x Grup etkileşimi ve grup ana etkisi bulunmamıştır ($p > 0,05$). VL için, 60°/sn hızda CON ve ECC kasılmalarının etkileri karşılaştırıldığında, *tHb*, O₂Hb ve Hb Diff seviyelerinin aynı hızda CON'da ECC'ye kıyasla daha yüksek olduğu, *SmO₂* ve HHb'de ise anlamlı bir fark bulunmadığı görülmüştür. Ek olarak, gruplar arasında Hb Diff, *tHb*, O₂Hb ve HHb açısından fark bulunmuştur. Voleybol sporcularının toplam kan akışı ölçümleri sedanter bireylerden daha yüksekti. BF için, CON ve ECC karşılaştırıldığında, Hb Diff voleybolcularda CON ve ECC 60°/sn sırasında sedanter bireylere kıyasla daha yüksekti. Hız açısından, 60°/sn ECC'deki Hb Diff ve O₂Hb, 60°/sn hızlı CON'dan istatistiksel olarak daha yüksekti ($p < 0.05$).

Çizelge 1. Voleybol sporcularında ve sağlıklı sedanter bireylerde VL kasının CON kasılması sırasında izokinetik hızların etkisi

			Grup *	Grup	Hız
60°/sn	180°/sn	300°/sn	Hız F	F	F
			p	p	p
			η ²	η ²	η ²

SmO ₂ (%)	Voleybol Sporcuları	63,15±11,83	62,37±11,55	63,53±11,09	0,960 0,395 0,064	0,203 0,656 0,007	4,427 0,021 0,240
	Sedanter	63,69±8,03	63,30±7,75	66,69±7,40			
Hb Diff (µM)	Voleybol Sporcuları	23,91±6,52	24,73±5,42	26,98±4,52	0,973 0,390 0,065	2,786 0,088 0,197	17,592 <0,001 0,557
	Sedanter	20,37±4,02	22,23±4,14	24,45±4,46			
tHb (µM)	Voleybol Sporcuları	138,30±17,05	139,09±18,01	141,70±20,13	0,949 0,393 0,032	9,170 0,005 0,240	9,809 <0,001 0,253
	Sedanter	116,33±22,28	117,58±22,53	118,49±23,15			
O ₂ Hb (µM)	Voleybol Sporcuları	81,30±8,42	81,78±8,32	84,24±10,05	0,585 0,561 0,020	10,776 0,003* 0,271	16,879 <0,001 0,368
	Sedanter	68,33±12,24	69,87±12,58	71,41±12,90			
HHb (µM)	Voleybol Sporcuları	57,00±10,03	57,31±10,38	57,46±10,57	1,636 0,214 0,104	6,757 0,015 0,189	0,424 0,659 0,029
	Sedanter	48,00±10,32	47,70±10,19	47,07±10,55			

Çizelge 2. Voleybol sporcularında ve sağlıklı sedanter bireylerde BF kasının CON kasılmaları sırasında izokinetik hızların etkisi

		60°/sn	180°/sn	300°/sn	Grup *	Group	Hız
					Hız F p η ²	F p η ²	F p η ²
SmO ₂ (%)	Voleybol Sporcuları	67,16±9,47	69,24±10,05	68,38±10,82	0,594 0,541 0,021	0,326 0,572 0,012	4,215 0,023 0,131
	Sedanter	69,06±5,79	70,26±6,11	70,73±5,61			
Hb Diff (µM)	Voleybol Sporcuları	22,26±5,32	23,47±4,06	25,02±4,94	0,502 0,608 0,018	0,608 0,442 0,021	7,591 0,001 0,213
	Sedanter	24,31±6,92	25,23±6,66	25,97±6,99			
tHb (µM)	Voleybol Sporcuları	125,70±19,84	125,94±20,20	131,30±22,44	1,423 0,249 0,048	2,506 0,125 0,082	1,182 0,314 0,041
	Sedanter	116,58±22,18	115,21±21,73	115,67±21,21			
O ₂ Hb (µM)	Voleybol Sporcuları	73,95±10,51	74,64±10,34	77,85±11,16	1,453 0,243 0,049	1,342 0,256 0,046	2,402 0,100 0,079
	Sedanter	70,44±14,21	70,17±13,89	70,80±13,82			
HHb (µM)	Voleybol Sporcuları	51,74±10,02	51,30±10,26	53,45±11,66	1,194 0,305 0,041	4,155 0,051 0,129	0,533 0,558 0,019
	Sedanter	46,14±8,24	45,03±8,05	44,87±7,62			

Tartışma

Çalışmalar, yüksek hızda yapılan egzersizlerin aksine yavaş hızda yapılan izokinetik egzersiz sırasında kas aktivitesinin arttığını göstermiştir. Denis, Wilkinson ve De Vito (2011) tarafından yapılan bir çalışmada, yazarlar açılal hızın VL ve rektus femoris kaslarındaki oksijen seviyeleri üzerindeki etkisini araştırmışlardır. Rekreatyonel olarak aktif olan on bir erkek birey, 30, 60 ve 120°/sn hızlarda maksimum eforla on diz ekstansiyonu gerçekleştirmiştir. NIRS kullanılarak bu kaslarda doku oksijenasyon indeksi (DOI) ve tHb ölçülmüştür.

Sonuçlar, 60°, 120° ve 240°/sn'lik hızlara kıyasla 300°/sn'de her iki kas DOI'sinde önemli bir düşüş olduğunu ortaya koymuştur. Ayrıca, SmO₂ seviyesinin açısal hız ile orantılı olarak arttığı bildirilmiştir. Bu sonuç bizim çalışmamızla paraleldir. Ancak ek olarak, tHb ve hız ile ters bir ilişki bildirmişlerdir. Bununla birlikte, çalışmamızda daha yüksek hız ile tHb'de bir artış bulduk. Bu farklılıkların, bizim çalışmamızda kullanılan hızlara kıyasla onların çalışmasında kullanılan hızların farklı olmasından kaynaklanabileceğini düşünmekteyiz.

BF için, çalışmamızda, Hb Diff'in 300°/sn sırasında 60°/sn'ye kıyasla önemli ölçüde daha fazla olduğu bulunmuştur ($p = 0.008$) ve SmO₂'de genel bir etki bulunmuştur, ancak sonraki ikili karşılaştırmalar (post-hoc testleri) herhangi bir spesifik fark ortaya koymamaktadır. Bu da fizyolojik tepkilerin karmaşıklığını göstermektedir.

Çalışmamızda, CON ve ECC kasılmalarının etkilerini 60 hızda karşılaştırdık, tHb, O₂Hb ve Hb Diff seviyelerinin aynı hızda CON'da ECC'ye kıyasla daha yüksek olduğunu, SmO₂ ve HHb'de ise anlamlı bir fark olmadığını bulduk. Bulgularımız, VL için, Muthalib ve arkadaşları (2009) tarafından yapılan ve biceps brachi kasının oksijenlenmesi açısından ECC ve CON kasılmaları arasındaki farkları araştıran bir çalışma ile tutarlıdır. ECC'deki bu düşük tHb, daha küçük bir maksimal kas kütesinin aktivasyonuna bağlanmıştır. BF için, hız açısından, 60°/sn ECC'deki Hb Diff ve O₂Hb, 60°/sn CON hızına göre istatistiksel olarak daha yüksekti. Bu farklılıklar, hamstringlerdeki anatomik ve farklı kas çalışma modelinden kaynaklanıyor olabilir.

Voleybol sporcularının toplam kan akışı ölçümleri sedanter bireylerinkinden daha yüksekti. Bu iyileşmeyi, voleybolcularda arteriyel kompliansın artmasının yanı sıra endotel aracılı vazodilatasyon veya intima-media duvar kalınlığında azalma ile ilişkilendiriyoruz. Ayrıca, sol ventrikül diyastolik fonksiyonunun fiziksel olarak aktif bireylerde kardiyorespiratuar zindeliği etkileyen önemli bir faktör olduğu düşünülmektedir, çünkü voleybolcular düzenli fiziksel aktivite yapmaktadır.

Sonuç ve Öneriler

Bu sonuçlar, VL kasının, önemli metabolik talepler getirmeden veya seans sırasında yorgunluk semptomlarına neden olmadan, oksijenasyonu ve kan akışını optimize etmek, performansı ve iyileşmeyi potansiyel olarak artırmak için daha yüksek hızlı egzersizlerden yararlanabileceğini göstermiştir.

HHb'de farklılık bulunmaması ve Hb Diff'de farklılık gösterilmesi, dikkatimizi HHb yerine oksijen ekstraksiyonunu ölçmek için Hb Diff parametresini (Hb Diff ölçmek için birincil değişkenimiz olmadığından) kullanmaya yöneltmiştir. HHb, tHb'deki değişikliklere karşı hassas olmadığından, Hb Diff'in izlenmesi, kas oksijen ekstraksiyonu ve kullanımının daha net bir göstergesini sağlayabilir ve gelecekteki araştırmalarda farklı egzersizler sırasında kas metabolik durumlarının daha doğru değerlendirilmesine yol açabilir.

VL'de, voleybol sporcularının toplam kan akışı ölçümleri sedanter bireylerinkinden daha yüksekken, BF'de voleybol sporcuları ve sedanterler arasında kan akışı ölçümlerinde grup farklılığı bulunmamıştır. Bu bulgu, voleybolda spesifik antrenmanın VL'deki vasküler adaptasyonları etkilediğini, ancak BF'de etkilemediğini ve kasa özgü antrenman adaptasyonlarını gösterdiğini düşündürülebilir.

VL'de, Hb Diff, tHb, O₂Hb 60°/sn'de CON'da ECC'ye göre daha yüksekken, HHb değerleri hızlar arasında herhangi bir farklılık göstermemiştir. BF'de, 60°/sn'de Hb Diff üzerinde önemli bir Hız x Grup etkileşimi etkisi görülmüş ve hem voleybol sporcuları hem de sedanterler için ECC sırasında CON'dan daha yüksek değerler görülmüş, hızlar arasında SmO₂, tHb veya HHb'de önemli farklılıklar bulunmamıştır. Bu durum, farklı kasların CON ve ECC egzersizlerine nasıl yanıt verdiği ve antrenmanın her kas grubunun özel ihtiyaçlarına ve fizyolojik tepkilerine göre özelleştirilmesine işaret etmektedir.

Rehabilitasyon ortamlarında, özellikle diz veya kuadriseps yaralanmalarından sonra, CON odaklı egzersizlerin dahil edilmesinin, iyileşme aşamasında kan akışını ve oksijen iletimini artırmaya yardımcı olabileceği ve daha hızlı ve daha etkili bir iyileşme sürecini kolaylaştırabileceği sonucuna varılabilir. Ayrıca, eksantrik hamstring egzersizlerinin dahil edilmesi, hamstringlerin kuvvetlendirilmesi ve genel performansın artırılması için faydalı olabilir.

NIRS cihazı, sporculardan çeşitli oksijenasyon ölçümleri kullanarak iç yük verilerinin toplanmasına olanak tanır. Antrenörler ve pratisyenler bu verileri antrenman (ve yarışma) parametrelerini değerlendirmek ve ayarlamak için kullanabilir. İç antrenman yüklerini daha iyi ölçmek için kalp atış hızı Algılanan Efor Oranı gibi geleneksel yöntemlerin yanı sıra kas oksijenasyonu ölçümlerini de dahil etmenin zamanı gelmiştir.

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SYMBOLS AND ABBREVIATIONS

The symbols and abbreviations used in this study are presented below with their explanations.

Symbols	Explanations
%	Percentage
°	Degree
Δ	Change
cm	Centimeter
min	Minute
kg	Kilogram
m	Metre
n	Number of cases
p	Level of statistical error
SD	Standard deviation
sec	Second
μM	Micromolar
Ma	Milliamperes
Hz	Hertz
kHz	Kilohertz
MET	Metabolic equivalent

Abbreviations	Explanations
ATT	Adipose tissue thickness
BF	Biceps femoris
BMI	Body mass index
Ca ²⁺	Calcium
CON	Concentric
ECC	Eccentric
Hb Diff	Hemoglobin difference
HHb	Deoxygenated hemoglobin

IPAQ	International physical activity questionnaire
IPAQ-SF	International physical activity questionnaire short form
ISAK	International society for the advancement of kinanthropometry
NIRS	Near-infrared spectroscopy
O₂Hb	Oxygenated hemoglobin
SmO₂	Muscle oxygen saturation
tHb	Total hemoglobin
TSI	Tissue saturation index
VL	Vastus lateralis



1. INTRODUCTION

Isokinetic dynamometers are specialized systems designed to assess the strength, power, and endurance of the desired muscle in real time [1]. This system can measure these variables across different speeds and types of contractions, including concentric (CON) and eccentric (ECC) contractions [2]. It's noted that these contractions have different metabolic characteristics at varying speeds [3]. Slow-speed contractions lead to increased recruitment of muscle fibers, due to increase in firing frequency to maintain the workload. Conversely, fast-speed contractions involve less muscle fibers recruitment [4].

Through the use of isokinetic dynamometry, it is possible to obtain information on the metabolic characteristics of various muscles across different speeds and contraction types. This information can be useful in designing tailored rehabilitation programs, implementing strategies for injury prevention, and effective personalized training regimens aimed at enhancing performance across diverse populations.

Over the past few years, Near Infrared Spectroscopy (NIRS) has gained popularity due to its ability to assess local muscle oxidative metabolism across different exercise modalities [5]. NIRS serves as a noninvasive optical method. It allows the ongoing monitoring of muscle oxygen saturation (SmO_2) and total hemoglobin (tHb) levels [6]. SmO_2 aims to evaluate how muscles use and take in oxygen, determining the balance between oxygen uptake and utilization in the muscle., while tHb measurements indicate alterations in the volume of small blood vessels [6,7].

By utilizing this physiological evaluation, it is possible to enhance training efficiency and maximize improvement in strength. It provides valuable information to the literature regarding specific protocols designed to achieve the magnitude and duration of metabolic stress with minimal fatigue [8]. It will also pave the way for future recommendations for training and recovery, especially in the context of anterior cruciate ligament rehabilitation.

Although the measurement of SmO_2 and tHb levels is important, there are very few studies on this subject. There is a gap in the literature regarding the SmO_2 and tHb levels of the vastus lateralis (VL) and biceps femoris (BF) during isokinetic contraction at varying speeds

(60, 180, 300°/s). Therefore, the main aim of this study was to investigate changes in SmO_2 and tHb levels during maximal CON and ECC contractions at speeds of 60, 180 and 300°/s while measuring muscle strength, power, and endurance of the VL and BF in the dominant leg.

Furthermore, it is important to investigate the effects of these parameter measurements in individuals with different levels of physical fitness, as different individuals may show differences in muscle contraction patterns, potentially resulting in differences in SmO_2 and tHb levels between muscle groups. A recent study highlights the profound effect of physical inactivity on skeletal muscle metabolism, revealing that it leads to increased fat accumulation and loss of muscle mass when energy balance is not maintained. In contrast, aerobic exercise improves athletes' physical functioning and increases skeletal muscle oxygen content [9].

In the literature, there are few studies comparing CON and ECC contractions metabolic characteristics. Our study will be the first study to compare metabolic characteristics of CON and ECC contractions in maximal knee circumference muscles between sedentary and athletes using NIRS. Therefore, the secondary aim of this study was to compare and analyze SmO_2 and tHb responses between different contraction types (CON and ECC) and velocities (60, 180, 300°/s) among healthy sedentary individuals and athletes. In this way, this information will be understandable not only for individuals who train regularly but also for sedentary individuals.

H0a: There is no difference in muscle oxygen saturation and total hemoglobin levels in Vastus Lateralis (knee extension) between sedentary individuals and athletes during isokinetic maximal concentric contractions performed at varying speeds.

H0b: There is no difference in muscle oxygen saturation and total hemoglobin levels in the Biceps Femoris (knee flexion) between sedentary individuals and athletes during isokinetic maximal concentric contractions performed at varying speeds.

H0c: There is no difference in muscle oxygen saturation and total hemoglobin levels in Vastus Lateralis (knee extension) between sedentary individuals and athletes during isokinetic maximal eccentric and eccentric contractions performed at varying speeds

H0d: There is no difference in muscle oxygen saturation and total hemoglobin levels in Biceps Femoris (knee flexion) between sedentary individuals and athletes during isokinetic maximal eccentric and concentric contractions performed at varying speeds.





2. BACKGROUND

2.1. Skeletal Muscles

Skeletal muscle constitutes roughly 40% of the human body's weight [10-12]. In the human body, skeletal muscle is one of the three major types of muscle tissue. Three primary muscle tissues are: skeletal, cardiac, and smooth. Skeletal muscles connect to bones via tendons, enabling movement throughout the body. During transitions from rest to vigorous exercise, blood flow to muscle tissue can surge nearly 100 times higher than at resting levels [13].

2.1.1. Anatomy of skeletal muscles

The muscle fiber, also known as the myofiber, is the smallest functional unit within skeletal muscle. It's a lengthy cylindrical cell containing numerous nuclei, mitochondria, and sarcomeres [14-16]. Surrounding each muscle fiber is a delicate sheath of tissue i.e, connective tissue known as the endomysium. Endomysium contains capillaries and nerve tissue, providing nourishment and innervation to each individual muscle fiber [17,18]. A muscle fascicle, alternatively termed a fiber bundle, comprises around 20 to 80 muscle fibers aligned parallel to each other [19]. The fascicles are surrounded by a denser layer of connective tissue referred to as the perimysium. The formation of a discernible muscle occurs by bundling together numerous muscle fascicles enveloped within a dense collagenous sheath that extends from the tendons, known as the epimysium.

2.1.2. Skeletal muscle at cellular level

Skeletal muscle fibers, characterized by their striped appearance and multiple nuclei, typically range in diameter from 10 to 100 micrometers and can extend over several centimeters [20, 21]. Situated at the outer edge of the cell, the nuclei are in close proximity to the sarcolemma. The sarcolemma, which encases each muscle fiber in a tubular structure, serves as a protective boundary that separates the internal cellular environment from the extracellular surroundings [22, 23]. Due to the presence of plasma membrane and a polysaccharide layer that blends with tendon fibers, the sarcolemma plays an important role in the integrity of muscle tissue [24]. The sarcolemma contains invaginations called transverse tubules, which play vital roles in facilitating ion exchange within the cell.

Skeletal muscle fibers are comprised of multiple myofibrils, varying from several hundred to several thousand in number. These myofibrils are predominantly made up of actin i.e., thin filaments, myosin i.e., thick filaments, and supportive proteins. The organization of actin and myosin within the myofibrils creates the striped pattern characteristic of striated muscle and establishes functional units called sarcomeres. Sarcomeres exhibit a longitudinal arrangement and contain identifiable structures including the M line, Z disk, H band, A band, and I band [25-29]. The Z line, referred to as the Z disk as well, delineates the outermost border of the sarcomere, functioning as a point of attachment for actin filaments facilitated by alpha-actinin [30]. Situated at the center of the sarcomere, the M line serves as a focal point where myosin filaments connect through binding sites within the myosin filament. Inside the sarcomere, the H band covers the M line and forms the central region containing exclusively myosin filaments. Spanning a substantial segment of the sarcomere, the A band encompasses all the myosin fibers and encompasses regions where actin and myosin filaments intersect. Covering the terminal areas of adjacent sarcomeres, the I band exclusively contains actin filaments. Throughout muscle contraction, the H and I bands experience reduction in length, whereas the A band remains unchanged in size.

Actin filaments, known as filamentous-actin, are structured as double helices and are formed from monomeric G-actin units [31]. G-actin exhibits polarity within the sarcomere, creating a positive and negative end, with the positive end oriented towards the terminal of the sarcomere [32-34]. Tropomyosin, a protein with a helical structure, lines up within the crevice of the actin double helix. Troponin is associated with tropomyosin, creating a complex that binds to every seven actin monomers [35]. Troponin-C, troponin-I, and troponin-T form this complex. Troponin-T interacts with tropomyosin, Troponin-I hinders the interaction between actin and myosin, and Troponin-C attaches to calcium [36-37].

Myosin proteins are composed of two parts: light meromyosin and heavy meromyosin [38]. The interaction between light meromyosin segments plays a crucial role in anchoring myosin at the M line [39, 40]. The heavy meromyosin segment segmented into two parts: S-1, recognized as the myosin head responsible for binding to actin and housing an ATPase element, and S-2, which serves as the site for the power stroke [41, 42].

Inside the sarcomere, several supporting proteins exist, such as titin, desmin, myomesin, C protein, nebulin, and plectin. Plectin serves the role of connecting the Z disks of adjacent

myofibrils [43, 44]. Desmin contributes to maintaining the alignment of myofibrils, forming connections with the cytoskeleton and other cellular components, and distributing contractile force [45, 46]. Myomesin and C protein function as proteins that bind to myosin, securing and stabilizing it at the M line [47]. Titin, positioned at the Z disk, plays a crucial role in longitudinally anchoring myosin within the sarcomere [48-50].

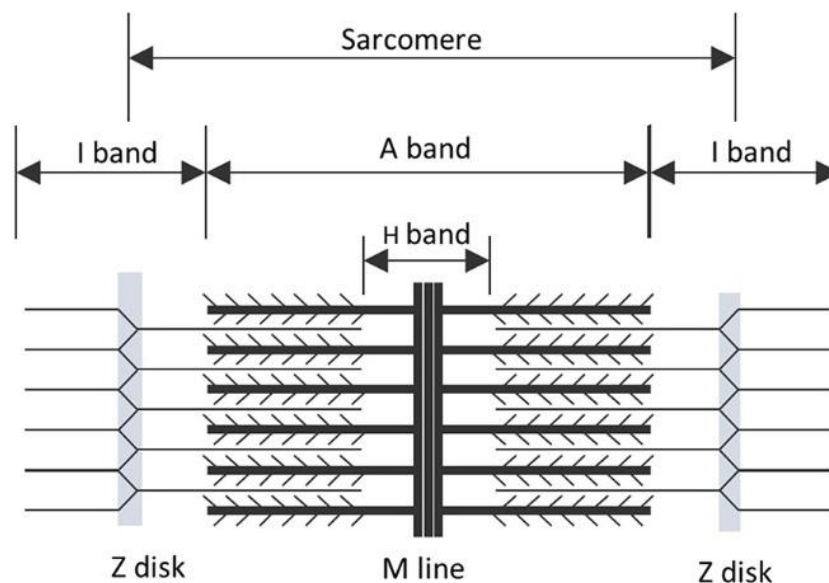


Figure 2.1. Skeletal muscle at cellular level

2.1.3. Excitation contraction coupling:

When fast sodium channels known as postsynaptic voltage channels are activated, an action potential is generated [51]. This action potential is then transferred to the fiber of the muscle, thereby instigating the contraction of muscle. This phenomenon, known as Excitation-Contraction Coupling. This takes place at the junction of two membrane systems: one is the T-tubules, and the other is sarcoplasmic reticulum.

Following the transmission of the nerve action potential, depolarization occurs in the dihydropyridine receptor located on the transverse tubules. That receptor functions as a voltage-gated calcium (Ca^{2+}) channel. This activation of it then triggers the substantial release of Ca^{2+} from the terminal cisternae of the sarcoplasmic reticulum through ryanodine receptors [52]. These receptors are Ca^{2+} release channels positioned on the membrane of the sarcoplasmic reticulum.

The main proteins responsible for the cycling and storage of Ca^{2+} within the sarcoplasmic reticulum are dihydropyridine receptor, ryanodine receptor1, and the sarco/endoplasmic reticulum calcium ATPase pump, working together with calsequestrin [53]. Calsequestrin, possessing a significant capacity for binding calcium ions, resides within tightly clustered filamentous formations located in the terminal cisternae of the sarcoplasmic reticulum.

2.1.4. Muscle contraction and force production

Generation of force and rapid movement occur in skeletal muscles through the contraction of sarcomeres [54]. These sarcomeres consist of thin and thick protein filaments, which are organized in alternating patterns. The composition of thin filaments includes α -actin along with its associated proteins. Thick filaments, on the other hand, comprise myosin and its associated proteins [55, 56].

In terms of function, the initiation of contraction commences when troponin-C binds with the calcium ions released during Excitation-contraction coupling. This interaction induces a conformational alteration in the troponin-tropomyosin complex, leading to the exposure of myosin binding sites on the actin filaments [57]. Subsequently, the myosin heads attach and move along the length of the actin filament, facilitating the hydrolysis of Adenosine triphosphate and ultimately resulting in contraction. The process involving the movement of myosin heads along actin filaments is referred to as the cross-bridge cycle. This cycle comprises a series of enzymatic reactions that drive the movement of myosin heads on actin filaments, resulting in the generation of force within each myofibril. This force is collectively perceived by the muscle [58].

2.1.5. Cellular events underlying force production

With the arrival of impulse, a conformational shift in troponin occurs due to the presence of free cytosolic Ca^{2+} , which reveals the sites where myosin binds to actin filaments [55].

- The myosin head extends outward toward the thin filament at a 45-degree angle, entering a rigid (stiff) state.
- Adenosine triphosphate that is accessible, binds to myosin, causing a brief separation of myosin from actin.

- The ATPase function of myosin breaks down adenosine triphosphate into adenosine diphosphate and phosphate, with phosphate remaining bound to myosin. This process causes the myosin filament to loosely reattach to actin at a 90-degree angle (cross-bridge) compared to the actin filament.
- The initiation of the power stroke occurs with the release of phosphate.
- The rotation of the myosin head around its hinge propels the actin filament forward, directing it towards the M-band.
- After completing the power stroke, the myosin head releases adenosine diphosphate and reverts to its rigid state [61].

2.1.6. Skeletal muscle fiber types

The human body consists of over 600 skeletal muscles primarily composed of elongated contractile cells known as muscle fibers [62]. These fibers are broadly categorized into two main groups: slow-twitch and fast-twitch [63, 64]. Fast-twitch fibers can then be split into two more types: intermediate fibers known as Type IIa and fast-glycolytic fibers referred to as Type IIx or IIB.

Slow-twitch fibers

These fibers, also referred to as Type I or red fibers, possess a higher oxidative capacity.

They are characterized by:

- A significant presence of mitochondria and a greater number of capillaries, which contribute to their ability to sustain prolonged activity.
- Longer excitation time and lower maximum shortening velocity.
- Well-suited for endurance exercises due to their high oxygen content, facilitating aerobic metabolism.

Fast-twitch fibers

These are also termed Type II or white fibers, exhibit higher glycolytic enzyme activity.

They are characterized by:

- Elevated ATPase activity, abundant creatine phosphate and glycogen content, resulting in brief excitation times and high maximum shortening velocities, enhancing maximal power.
- Well-adapted for anaerobic metabolism.
- Predominantly found in athletes who engage in short, rapid movements, such as power lifters.

Notably, Fast-twitch Type A fibers have the capacity to produce approximately five times more power than slow-twitch fibers, while fast-twitch Type X fibers are nearly twice as powerful as fast twitch A fibers [65].

2.1.7 Muscle fiber transition with level of activity

The skeletal muscles are highly adaptable tissues when exposed to lifting heavy weights, exercising, or a sedentary lifestyle. In healthy adult human skeletal muscle, it is widely accepted that changes in fiber type composition occur, transitioning between Type IIx. => Type IIa, => and Type I fibers. Prior research indicates that increased neuromuscular activity tends to induce transitions from fast to slow fiber types, while reduced neuromuscular activity typically results in changing from slow to fast fiber types [66].

Previous research suggests that resistance training among healthy individuals commonly leads to reduction in Type IIx muscle fiber content, accompanied by an increase in Type IIa fibers. Conversely, studies have suggested that lack of exercise and inactivity may promote transitions between slow and fast-twitch muscle fiber types, resulting in an increase in Type IIx fibers.

In the scope of our study, the subjects are volleyball athletes and sedentary individuals. Studies have shown that, volleyball athletes are predominantly reliant on type IIA muscle fibers, which are characterized as fast-twitch and intermediate [67]. These muscle fibers utilize both aerobic and anaerobic metabolism, given that Type IIA fibers represent a combination of Type I and Type II muscle fibers [68]. While sedentary typically possesses higher proportion of Type IIX fibers [69].

2.1.8. Muscles of interest

Table 2.1. Muscles of interest

Anterior Muscles of the Thigh (Quadriceps)	Posterior Muscles of the Thigh (Hamstrings)
RF: Rectus Femoris	SM: Semimembranosus
VL: Vastus Lateralis	ST: Semitendinosus
VM: Vastus Medialis	BF: Biceps Femoris • long head • short head
VI: Vastus Intermedius	

From superficial=>intermediate=> deep layer

In the scope of our study, the muscle of interests is VL and BF.

Vastus lateralis (VL)

The vastus lateralis muscle originates from various points on the proximal femur, including:

- *Origin:* It's on the line between the trochanters, the larger trochanter, the outer aspect of the linea aspera, gluteal tuberosity, and the lateral septum between muscles.
- *Insertion:* It's on the lateral aspect of the patella and ultimately attaches to the tibial tuberosity via the patellar tendon.
- *Action:* It primarily acts as a knee extensor.
- *Fiber characteristics of VL:* The vastus lateralis muscle displays a mixture of both fast- and slow-twitch fibers. One study revealed that around 40% of the muscle comprises type I fibers, 30% consists of type IIa fibers, and 20% is composed of type IIb fibers [62,70].

Biceps Femoris (BF)

It consists of two heads of origin. long head and short head.

Table 2.2. Biceps femoris muscle

Biceps Femoris	Origin	Insertion
Long Head	Ischial tuberosity and the lower part of the sacrotuberous ligament.	These two muscular heads combine and insert into the

Short Head	The outer edge of the linea aspera, the upper two-thirds of the supracondylar line, and the lateral intermuscular septum.	head of the fibula, the crural fascia, and the upper part of the tibia.
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- *Action:* It involves primarily knee Flexor. Additionally, this muscle contributes to hip joint extension, lateral leg rotation, and has a role in knees with anterior cruciate ligament deficiency [71,72].
- *Fiber characteristics of BF:* The muscle fibers also show a blend of type 1, 2a, and 2× (2b) fibers [69].

2.1.9. Muscle Mode of Action

Skeletal muscles contract through either shortening, known as CON action, or lengthening, known as ECC action [73, 74].

Concentric contraction

This takes place when a muscle contracts, reducing its length, and produces force to perform positive work. The force produced is transmitted through the tendon to the joint, facilitating movement and altering the joint angle. An example of concentric action is lifting weights.

Eccentric contraction

It takes place when the muscle lengthens, producing force to execute negative work. It facilitates the dissipation of mechanical energy during body deceleration. It also enables the transformation of kinetic energy into the elastic energy stored in tendons.

Both types of contractions differ significantly from each other in terms of mechanical and neural aspects [75].

2.2. Isokinetic Systems

Isokinetic devices serve as reliable tools for conducting isokinetic strength tests, commonly utilized in laboratory environments [76]. The device comprises three components: a dynamometer, a testing platform, and a computer system. They offer a means for objectively

evaluating muscle strength performance in both eccentric and concentric contractions [77]. Data gathered from these instruments can be analyzed separately to assess the strength of the dominant and non-dominant extremities.

This technology has become extensively utilized in tracking the progress of rehabilitation, particularly in assessing readiness for resuming sports activities following injuries to the anterior cruciate ligament [78]. In this context, clinicians evaluate the strength of muscles, i.e., Quadriceps and Hamstrings, in individuals, including both athletes and non-athletes.

The isokinetic system serves diverse objectives, and the advantages of these systems are outlined below:

Advantages of isokinetic system

- It is safe due to its accommodating resistance factor.
- It offers valid objective recording of the real-time functioning of muscles
- It enables the reporting of muscular endurance, strength, and power.
- It allows tracking and monitoring of progress records during intervention or rehabilitation.
- It facilitates comparison between the dominant and non-dominant extremities and reports any agonist and antagonist imbalances.
- For patient motivation, it provides real-time visual feedback during exercise.
- It permits exercises and tests to be performed at different velocities and contraction types.
- It enables participants to apply maximal force throughout the range of motion, producing resistive torque according to the individual's effort applied [79 80].

Limitations of isokinetic system

- High Cost
- Application of nonfunctional movement patterns.
- Constraints in replicating actual speeds observed in sports performance due to limited velocity options.
- Elevated joint compressive forces experienced during slower movements.

- The potential for increased anterior movement of the tibia during assessment or rehabilitation when utilizing the complete range of motion.
- Operation requires well-trained personnel due to its complexity.

Contraindications of isokinetic system:

- Acute strains in muscle-tendon units, ligament, or capsule injuries,
- Limitations in the healing process of soft tissue,
- Intense discomfort or pain,
- Significantly restricted range of motion,
- Significant swelling and instability in the joint.

Isokinetic Terms

- *Torque*: It is defined as the application of force around an axis, leading to rotational motion. Its unit is Newton-meter (Nm).
- *Peak torque*: It is defined as the highest level of torque produced by muscle contractions during the movement of a limb across its full range of motion. It is absolute value.
- *Peak torque/body value*: The maximum torque produced according to each person's body weight.
- *Force*: It is defined as the physical property that stops or starts motion. Its unit is Newton.
- *Average velocity*: It is described as the rotational distance covered within a specific duration of time. Its unit is degrees per second ($^{\circ}/s$).
- *Work*: It is defined as by the force produced over a particular distance. Its unit is Newton-meter (Nm)
- *Power*: It is used to denote the amount of work performed within a given timeframe. Its unit is Watt.

Isokinetic dynamometry enables the assessment of muscle function with consistent resistance, maintaining a constant angular velocity, thus facilitating optimal force generation throughout a specified range of motion. For knees, the commonly used velocity spectrum for testing includes angular velocities of 60, 180, and 300 $^{\circ}/s$, corresponding to slow, moderate, and high speeds of motion [81].

Since isokinetic testing is a reliable method for evaluating muscle performance, therefore it allows testing of both concentric and eccentric contractions of the knee flexors (quadriceps) and knee extensors (hamstrings).

2.3. Blood Supply

2.3.1. Blood vessels within skeletal muscle

Blood supply to skeletal muscles arises from main arteries, which represent the last branches of arterial circulation before penetrating the muscle tissue [82]. These main arteries are evenly distributed along the length of the muscle and generate feeder arteries that extend towards the muscle's outer layer (epimysium) at angles perpendicular or oblique to the main arteries. Feeder arteries contribute significantly to blood flow resistance in skeletal muscle, comprising about 30–50% of total resistance, thus serving as crucial sites for flow of blood regulation prior to reaching the micro vessels within the muscle tissue [83-86]. Secondary arteriolar branches arise at right angles to these feeder vessels and extend longitudinally. This network of arterioles includes branching vessels that originate from feeder arteries as they penetrate the muscle tissue [87]. Arterioles pierce through the perimysium and travel at right angles to the axis of muscle fibers until they reach terminal branches. These branches then split into numerous capillaries that are embedded within the endomysium, running parallel to the muscle fibers. The terminal arterioles constitute the ultimate branches comprising vascular smooth muscle, and the group of capillaries supplied by a terminal arteriole is referred to as the microvascular unit. This unit serves as the smallest functional entity for controlling blood flow in skeletal muscle [88].

Every muscle fiber is surrounded by multiple capillaries, which, when viewed in cross-section, exhibit a highly variable arrangement around the fiber. This variability, combined with the varying circumference of each muscle fiber, suggests that oxygen distribution within skeletal muscles is not uniform, even when capillary recruitment is maximized [89]. However, the interconnected nature of the capillaries surrounding each fiber helps reduce this non-uniformity, as the density of parallel capillary segments rises towards the venular end of the network. While true capillaries within skeletal muscle typically measure around 4 μm in diameter, they expand as they near postcapillary venules [90]. When examining the anatomy of capillary networks in red and white muscle, it becomes evident that oxidative

muscle exhibits a higher density of surrounding capillaries and connections between neighboring capillaries.

2.3.2. Basal hemodynamics

At rest, skeletal muscle exhibits low oxygen consumption, resulting in a comparatively lower average muscle blood flow rate of 5 to 10 ml/min/100 g [90, 91]. However, during intense muscular activity, such as maximal exercise, skeletal muscle blood flow can surge to 80–100 milliliters per minute per 100 grams in certain areas, a substantial increase necessary to meet the heightened demand for oxygen, which can be 20 to 50 times greater [91].

During periods of inactivity, the resistance arteries in skeletal muscle maintain a partial constriction, known as basal vascular or vasomotor tone [92]. This baseline level of vascular smooth muscle contraction is crucial for sustaining this state. Changes in vascular smooth muscle contractile activity from its baseline level result in modifications in the diameter of resistance arteries, termed variations in vascular or vasomotor tone [93].

Factors impacting vasomotor tone are divided into two categories: central (remote) control mechanisms and local intrinsic influences that trigger either contraction or relaxation of vascular smooth muscle within the tissues [94]. In central control processes affecting blood flow to skeletal muscles, there are neural and humoral inputs at play. Conversely, local regulatory mechanisms involve metabolic, mechanical, endothelial, and paracrine factors [95,96].

2.3.3. Oxygenation of tissues

Oxygen is delivered to skeletal muscle fibers by the blood through microcirculation. The partial pressure of oxygen (PO_2) is determined by the balance between oxygen supply and utilization consumption, whether at rest or during physical activity [97]. Oxygen consumption is calculated as total blood flow denoted as Q and the differences in oxygen concentration between the arteries and veins, represented as $(A - V)O_2$ [98]. Oxygen is transported from the bloodstream to the mitochondria in skeletal muscles through the following three mechanisms:

- Oxygen Delivery

- Diffusion of Oxygen
- Utilization of Oxygen via Mitochondria

Oxygen delivery

The factors i.e., rate of the blood flow to the muscle and concentration of arterial oxygen determine the total oxygen delivery to tissue. Hemoglobin (Hb) is the main carrier of oxygen and the proportion of Hb bound to oxygen is expressed as percent saturation. It is influenced by the PO_2 in arterial blood. Typically, in healthy individuals, Hb is almost entirely saturated with oxygen when the arterial PO_2 is around 100 mm Hg [99,100].

Diffusion of oxygen

Oxygen is transported to the exchange vessels through the bloodstream and must then move from the capillaries into the mitochondria within skeletal muscle cells by diffusion. The variation in oxygen tension between the exchange vessels and the skeletal muscle myocytes creates the necessary gradient that drives the diffusion of oxygen from the blood into the mitochondria. Factors such as the oxygen content within micro vessels, functional capillary density (indicating the number of open capillaries), and the available surface area for gas exchange significantly influence the delivery of oxygen through diffusion. In resting skeletal muscle, about one-fourth of the capillaries are actively allowing blood flow at any moment [101].

The density of capillaries varies according to the oxidative capacity of muscle fibers [102]. Slow-twitch oxidative fibers typically receive approximately three times the number of capillaries per fiber compared to fast-twitch glycolytic fibers. It also varies in terms spatial arrangements [103]. In white muscle fibers, most capillaries run parallel to the fibers' long axis [104]. Conversely, in red muscle fibers, capillaries take a more convoluted path, forming loops. This configuration enhances oxygen exchange efficiency by increasing surface area and reducing the distance for oxygen diffusion in oxidative fibers [104].

Utilization of oxygen via mitochondria

Oxygen eliminates reducing equivalents from cytochrome a_3 , which serves as the final oxidase in the respiratory chain. Consequently, the pace of mitochondrial oxygen consumption is governed by the cellular PO_2 and the level of reduced cytochrome a_3 [105,90].

2.3.4. Muscle pump

During rhythmic exercise, as muscles contract, there is a rise in extravascular pressure, leading to compression of the embedded vasculature. In veins with valves, there is an elevation in the arterio-venous pressure gradient, directing the flow towards the heart. This functions as a muscle-pump and during physical activity, this pump functions as an additional mechanism to aid in blood circulation throughout the vascular system by boosting venous return. The directed movement of blood towards the center is made possible by the existence of unidirectional valves within larger veins. These valves remain open during muscle contractions but close upon muscle relaxation [90].

2.4. Near Infrared Spectroscopy

Human skeletal muscle contracts in either a CON or ECC manner, each exhibiting differences in mechanisms of force generation and metabolic energy expenditure [106]. Understanding the responses of skeletal muscle tissue during these different contractions is vital in sports and musculoskeletal rehabilitation. This data facilitates the assessment of individuals' adaptation to training or rehabilitation interventions. While numerous systemic parameters such as heart rate, blood lactate concentration, and maximal oxygen uptake are commonly used for monitoring training outcomes, they offer limited insight into muscle-specific responses [107]. To address this gap, NIRS has emerged as a non-invasive method for examining muscle response, providing valuable insights into physiological understanding.

NIRS was first utilized by Glenn Allan Millikan to evaluate oxygen levels within muscle [108]. In 1977, Frans Jobsis discovered the distinct absorption patterns of near-infrared light

by oxygenated and deoxygenated Hb and myoglobin (Mb) in 2-4 cm under muscle tissues [109].

Generally, NIRS utilizes the longer wavelengths found in the near-infrared segment of the electromagnetic spectrum, ranging from 700 nm to 1000 nm [110, 111]. This wavelength range encounters reduced scattering and can effectively penetrate living tissue. Light emitted by the source traverses through the tissue until it reaches the light detector of the NIRS probe. However, a portion of the near-infrared light is either absorbed or scattered within the muscle tissue before reaching the detector [112]. Heme compounds present in both Hb and Mb deflect or scatter the flow of infrared light.

Given that oxygen molecules bind to heme for transportation through the bloodstream, the degree of light absorption by these compounds serves as an indicator of the oxygen levels within a particular tissue [113]. Subsequently, the reflected light is captured by a detector(s), where a set of algorithms and computations generate a reliable muscle oxygen saturation (SmO_2) [114]. The foundation of NIRS lies in the Beer-Lambert law, which stipulates that light passing through a medium containing colored compounds undergoes absorption by those compounds, leading to a decrease in the intensity of the emerging light which allows non-invasive measurements [115]. This principle forms the basis for calculations in all NIRS instruments.

NIRS signals rely on assessing the light absorbance of heme groups found in Hb within the vascular system and Mb within muscle tissue [116]. Near-infrared light has the capacity to permeate through several millimeters into biological tissue. The primary chromophores in skeletal muscle tissues that absorb this light are Hb, Mb, and cytochrome oxidase (cytox) [113]. Studies have demonstrated that the contribution of cytox *in vivo* represents less than 5% of the total absorption, suggesting that the primary molecules responsible for the signal are Hb and Mb. However, the precise role of each molecule in generating the signal is still under discussion [113].

Hb has the capability to attach four oxygen molecules, while Mb only binds one. In NIRS, both oxygenated forms (HbO_2 , MbO_2) and deoxygenated forms (HHb, HMb) of Hb and Mb collectively contribute to the detection of oxygenated (HbMbO_2) and deoxygenated (HHbHMb) signals, respectively. NIRS stands out for its ability to distinguish and measure

the O₂Hb/Mb and HHb/Mb. This differentiation enables the assessment of total hemoglobin concentration $[t(Hb+Mb)=(O_2Hb+Mb)+(Hhb+Mb)]$, thereby facilitating the measurement of blood flow in skeletal muscles, as well as oxygenation levels, and oxygen consumption [117].

Therefore, NIRS generates four signals:

- Oxygenated hemoglobin (O₂Hb/Mb),
- Deoxygenated hemoglobin (HHb/Mb),
- tHb/Mb calculated as: the sum of O₂Hb/Mb and Hhb/Mb, denoted as O₂Hb/Mb + Hhb/Mb.
- SmO₂ in percentage, alternatively referred to as tissue saturation. It is determined by the ratio of O₂Hb/Mb to t(Hb/Mb), denoted as $O_2 (Hb/Mb)/t(Hb/Mb)$ [117, 21].

This tool possesses significant potential in advancing our understanding of skeletal muscle hemodynamic across diverse populations, applicable to both athletic and non-athletic populations [118,119].

NIRS devices may vary slightly in the number of light sources and detectors. Early NIRS devices primarily focused on assessing brain oxygenation and were characterized by their large size, high cost, and immobility [118]. However, recent advancements have yielded more portable and wireless NIRS monitors. Example includes the PORTAMON by Artinis Medical Systems, Netherlands, the MOXY monitor from Fortiori Design, LLC, Minnesota, and TRAIN.RED FYER, enabling researchers to investigate SmO₂ for a wide range of exercise training modalities such as skiing, speed skating, cycling, running, rowing and Isokinetic [118,120, 121].

Notably, throughout the rest of this dissertation, we will use the following terms: O₂Hb for oxygenated hemoglobin (Oxy-Heme), HHb for deoxygenated hemoglobin (De-oxy Heme), tHb for total hemoglobin, and SmO₂ for muscle oxygen saturation, unless specified differently.

2.4.1. Principal of spectroscopy:

The foundation of NIRS principles stems from traditional spectroscopy principles, which have been adapted to suit biological tissue. Spectroscopy is a method utilized to determine the quantity of a molecular substance present in a homogeneous solution [122]. It operates on the Beer-Lambert law [123], which defines a direct correlation establishes between absorbance and the concentration of compound at a specific wavelength, represented as:

$$\text{Equation } OD_{\lambda} = \log (I_0/I) = \epsilon_{\lambda} \cdot c \cdot l$$

Here,

- OD_{λ} denotes the optical density measurement of the medium,
- I_0 represents for an initial light intensity,
- I represent the measured light intensity at a detector,
- ϵ_{λ} refers to how strongly the chromophore absorbs light, which is measured in units of $\text{mM}^{-1} \cdot \text{cm}^{-1}$.
- c stands for the amount of the substance present in the solution.,
- l indicates separation between the source of light and the detector.

As light travels from source and enters the solution, a portion of it will be absorbed by the colored compounds present in the medium. When the concentration of the compound in the medium is lower, less light is absorbed and allowing more light to the detector. Conversely, when the concentration of the compound in the medium is higher, more light is absorbed, resulting in less light reaching the detector [122,124-126].

This approach entails certain prerequisites. Firstly, the molecular compound under investigation must possess a light-absorbing chromophore. Secondly, the wavelength of the emitted light should be tailored to the specific chromophore. Thirdly, it's essential that there are no additional molecules in the solution containing chromophores that absorb light at the identical wavelength. Finally, the light must follow linear path through a homogeneous medium without scattering to ensure that any disparity in the intensity of light from the light emitter to the light detector is solely caused by the absorption of the specific molecular compound being targeted [122].

2.4.2. Spectroscopy in tissue

Spectroscopy faces numerous challenges when utilized in the examination of biological tissue. It requires light wavelengths that can penetrate through layers of skin, fat, and muscle tissue, reaching specific molecular targets within.

Light wavelengths

- Below 300 nm and above 1000 nm: are fully absorbed by water molecules and are therefore unsuitable.
- Between 450 nm to 650 nm: light is also absorbed entirely by Hb and other light-absorbing molecules known as chromophores.

However,

- Between 700 to 1000 nm in the near-infrared spectrum: light absorption is minimal enough to allow detection across significant depths of tissue. This range also coincides with the peaks of absorption spectra for both oxy and deoxy forms of Hb. Moreover, there is speculation that the hemoglobin concentration measured by NIRS primarily originates from blood vessels smaller than 1 mm in diameter, as larger vessels fully absorb near-infrared light.

In addition to the choice of light wavelength, spectroscopic methods encounter various obstacles when applied to biological tissue. These encompass the existence of numerous absorbing chromophores within the sample, non-linear propagation of light, and the tissue's non-uniform scattering characteristics. The decrease in light intensity from the emitter to the receiver is not solely due to absorption by the target molecule, it's also influenced by the absorption of chromophores with both fixed and variable concentrations, as well as by light scattering [122, 127,128]. Different NIRS technologies and instruments have emerged to tackle these obstacles [129].

2.4.3. NIRS sensors technology

Three primary technologies utilized for assessing SmO₂ and tHb include:

- Continuous wave (CW),
- Time resolved (TRS),
- Frequency domain NIRS.

These methods involve using different ways to improve NIRS measurements.

One method is using a correction factor based on literature, like in continuous-wave NIRS. Another approach is measuring how long it takes for light to travel after being emitted, as in time-resolved NIRS or tracking changes in the phase and strength of light signals, as in frequency-domain NIRS.

The NIRS Device (TRAIN.RED) in our study utilizes Continuous wave technology.

Continuous wave

Continuous wave spatially resolved spectroscopy (cw-NIRS) is the most common NIRS technology. It's easy to understand and portable. The key advantages of this technology over others are its cost-effectiveness and user-friendliness. Unlike other NIRS methods, continuous-wave NIRS doesn't require expensive laser diodes and doesn't need frequent adjustment [122, 130]. This technology relies on a modified version of the Beer-Lambert law.

$$\text{Equation } OD_{\lambda} = \log (I_0/I) = \epsilon_{\lambda} \cdot c \cdot l \cdot \text{DPF}$$

As we mentioned earlier,

- OD_{λ} denotes the optical density of the medium,
- I_0 represents for an initial light intensity,
- I represent the measured light intensity at a detector,
- ϵ_{λ} refers to how strongly the chromophore absorbs light,
- c stands for the amount of the substance present in the solution,
- l indicates separation between the source of light and the detector.
- While DPF, Differential Pathlength Factor is a factor, that considers how light is absorbed and scattered, allowing for the calculation of hemoglobin concentrations [122].

The DPF is specific to different wavelengths of light and can be affected by varying thicknesses and alterations in the optical properties of tissue layers like adipose tissue and skeletal muscle. In our study, to ensure consistency and accuracy, we maintained consistent adipose tissue thickness across all our individuals.

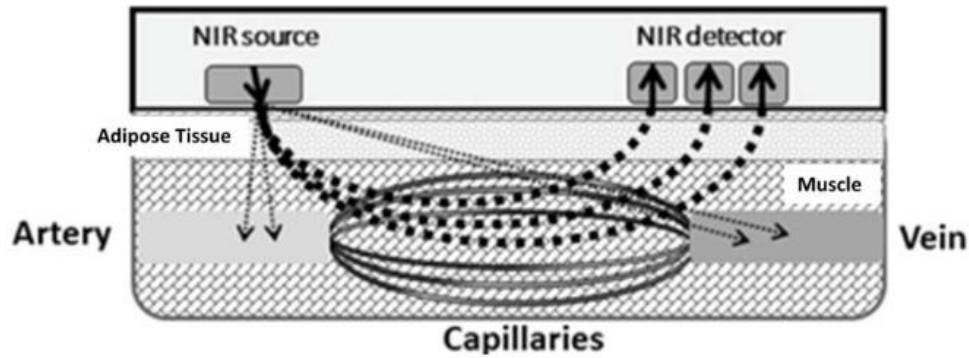


Figure 2.2. NIRS technology representation

2.4.4. Train.Red FYER

The Train.Red FYER functions as a continuous wave NIRS sensor. It is characterized by its compact size measuring at approximately 1.2 x 4.4 x 5.9 cm (0.5 x 1.7 x 2.3 in) in size and minimized weight design, weighing just 24 grams [131]. This sensor has one light emitting diode that emits light at two different wavelengths, 760 nm and 850 nm. It also has a line receiver with 64 pixels positioned at a midrange of 35 mm apart. The sensor can connect to a smartphone app using Bluetooth [131, 132]. This allows us to collect and export data at a rate of 10 times per second. For securing the sensor onto the subjects' thigh, a specific strap was utilized. The strap was made of stretchable fabric, integrates four anti-slip silicone stripes to ensure stability and prevent sliding on the limb.

While the sensor itself has not undergone validation, its design is based on the well-established PortaMon model from Artinis Medical Systems, which has been thoroughly validated and extensively utilized in prior research [132].

2.4.5. NIRS metrics

Terminology definition

- *O₂Hb*: It is an oxygenated Hb as reflecting oxygen supply in the microvasculature.
- *HHb*: It is deoxygenated Hb as reflecting microvascular oxygen extraction.
- *SmO₂*: It is called muscle oxygen saturation and is utilized to assess how much oxygen is delivered to the muscles versus how much is used up. It is measured as a percentage within the small blood vessels of the skeletal muscles, expressed as, $SmO_2 = [(O_2Hb)/(tHb)] * 100$.
- *tHb*: It is called total Hb concentration. It is used to assess alterations in the volume of blood in the small blood vessels.
- *Hb Diff*: It is the difference between *O₂Hb* and *HHb*.

The main aim of this study was to investigate changes in *SmO₂* and *tHb* levels during maximal CON and ECC contractions at speeds of 60, 180 and 300°/s of the VL and BF in the dominant leg. By utilizing this physiological evaluation, it is possible to enhance training efficiency and maximize improvement in strength. It provides valuable information to the literature regarding specific protocols designed to achieve the magnitude and duration of metabolic stress with minimal fatigue.

The secondary aim of this study was to compare and analyze *SmO₂* and *tHb* responses between different contraction types (CON and ECC) and velocities (60, 180, 300°/s) among healthy sedentary individuals and athletes. In this way, this information will be understandable not only for individuals who train regularly but also for sedentary individuals.



3. MATERIALS AND METHODS

3.1. Research Participants

The research was carried out within the Athlete Health Unit of the Department of Physiotherapy and Rehabilitation at Gazi University's Faculty of Health Sciences. To achieve a power of $\beta = 0.8$ with $\alpha = 0.05$, an a priori sample size calculation was conducted using G*Power software (version 3.1). This calculation utilized previously reported data for measuring muscle oxygenation amplitude during a sustained MVC task, comparing ECC and CON contractions using NIRS [189].

Our study involved 17 licensed elite volleyball athletes and 14 healthy sedentary individuals. For the study approval, prior to commencing our research, an application was submitted to the Gazi University Research Ethics. Permission from the ethics committee was granted on December 26, 2023, marking the initiation of our study (APPENDIX-1).

3.1.1 Inclusion criteria for athletes in the study

- Licensed elite athletes
- Age range between 18 and 35 years
- Body Mass Index (BMI) below 30 kg/m²
- Percentage of body fat not exceeding 35(%)
- Thickness of adipose tissue (ATT) less than or equal to 17.5 mm
- Absence of lower limb injuries within preceding 3 months
- No reported lower extremity pain within the last month
- Absence of any injuries to bones, joints, or the musculoskeletal system affecting physical activity
- Absence of any chronic disease such as diabetes mellitus, vascular diseases, or a history of abdominal surgery or appendicitis
- Who do not smoke or drink alcohol
- No history of the substance or drugs that boosts the performances

3.1.2 Exclusion criteria for athletes in the study

- Presence of lower extremity injuries within previous three months
- Reported lower extremity pain within the past month
- Documented injuries to bones, joints, or the musculoskeletal system impacting physical activity
- History of utilizing substances or drugs that enhance performance

These inclusion and exclusion criteria were similarly applied to the sedentary group of healthy individuals, with the exception that they do not participate in regular physical activity. They are required to be sedentary as per the International Physical Activity Questionnaire (IPAQ-short form (SF)).

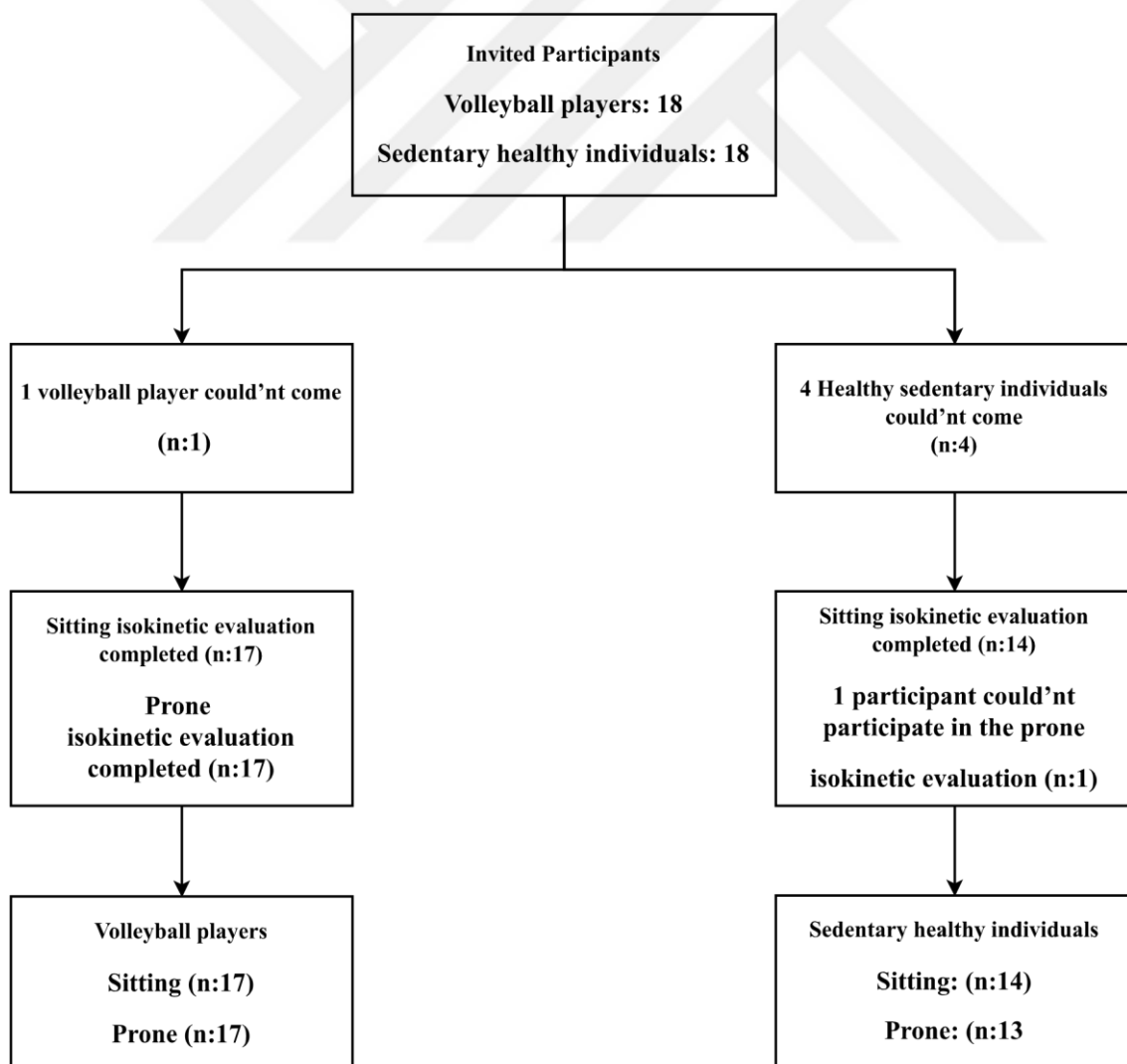


Figure 3.1. Flow chart

IPAQ-SF

This stands as a widely used self-assessment tool for evaluating physical activity and sedentary behavior in individuals aged 15-69 years [133, 134]. It was originally developed by Craig. It is globally acceptable validity and reliability [135]. The Turkish iteration of IPAQ-SF (IPAQ-SF-T) has been validated and established as a reliable instrument through prior research [136]. In this study, IPAQ-SF-T has been utilized to evaluate the level of physical activity among participants.

The questionnaire contained 7 questions. Participants reported how often they have been engaged in physical activity. They have detailed the duration of their activities across various intensity levels. This includes light, moderate, and vigorous activity. Additionally, participants have indicated their average daily sitting time per week [133].

The data was transformed into MET-min/week (metabolic equivalent). Total weekly MET-min physical activity was determined using MET values. The respective values for walking, engaging in moderate-intensity physical activities, and vigorous-intensity physical activities are 3.3, 4.0, and 8.0, as indicated. The calculation was multiplied with the MET value by the duration of activity each day and the frequency of activity per week [137].

The weekly total MET-minutes were calculated by summing across various areas of activity. This provided a calculated approximation of the total reported weekly physical activity [138]. Subjects were categorized into 3 categories based on their weekly total metabolic equivalent task, following the original IPAQ-SF scoring protocol [135, 139, 140].

- *Inactive*: With fewer than 600 MET minutes per week),
- *Minimally active*: Within the range of 600 to 3000 MET-minutes per week.
- *Highly active*: Surpassing 3000 MET-minutes per week.

Participants with little to no physical activity were categorized into the sedentary group.

3.2. Method

Before initiating the study, athletes and healthy sedentary subjects received detailed information regarding the study's content (APPENDIX-2). Participants then read and signed

relevant forms, confirming their understanding and agreement. The evaluations took place at the Athlete Health Unit within the Department of Physiotherapy and Rehabilitation at Gazi University's Faculty of Health Sciences.

Participants in the study underwent a 5-minute warm-up session using a bicycle ergometer before the evaluations. Subsequently, the evaluations were conducted in the following sequence.

- Gathering demographic data
- Analysis of Body Composition
- Measurement of Skinfold Thickness
- Assessment of ISOKINETIC Testing with NIRS Technology

3.2.1. Gathering demographic data

Two groups were included: elite volleyball athletes and sedentary individuals, as determined by the IPAQ with little to no physical activity. Prior to the assessment, the individual's personal details including their full name, age, height, profession, years of involvement in sports, specific positions played, and any past injuries were gathered verbally and documented on the evaluation form (APPENDIX-3,4).

3.2.2. Analysis of body composition

The participants underwent segmental body analysis using the TANITA BC 418 body composition device [141]. It functions as a means of measuring body composition. Specifically, it measures parameters such as fat mass and muscle mass. This measurement is achieved by analyzing bioelectrical impedance within the body [141]. This impedance relies on the difference in electrical conductivity between muscle tissue and fat. Fat within the body restricts the flow of electricity, allowing minimal passage. Conversely, water, abundant in muscles, facilitates the easy flow of electricity. Therefore, transmission of current between electrodes depends on the presence of conductive substances within the body, specifically sodium and potassium. The bloodstream contains elevated levels of these conductive materials, facilitating the predominant flow of electric current through this medium. In contrast, muscles contain moderate levels, while fat, bone, and air exhibit

3.2.3. Measurement of skinfold thickness

Before placing the NIRS device, skinfold thickness over the VL and BF muscles was measured using a caliper (model: 12-1110). Due to its potential impact on NIRS signal amplitude, we needed to calculate the thickness of adipose tissue, which is half of the skinfold depth. Hence, the measured skinfold thickness was divided by two. This division aimed to ascertain the thickness of the adipose tissue, encompassing both fat and skin layers, which encase the muscle beneath [147, 148].

For both the BF and VL muscles separately, the skinfold thickness was determined by averaging two measurements [149]. The measurements were conducted at the NIRS device location using a caliper [150]. These measurements adhered to the guidelines provided in The International Society for the Advancement of Kinanthropometry (ISAK) protocol [151-154].

ISAK protocol

Human body dimensions, including lengths, widths, circumferences, and skinfold measurements, are taken using surface landmarks as reference points. Taking this measurement is called Anthropometry. These procedures adhere to specific measurement guidelines established by ISAK, the globally recognized authority on anthropometric standards.

VL

The subjects were laid down supinely in a relaxed position. Then the distance between the spina iliaca anterior and the superior posterior edge of the patella was taken. A minor horizontal indicator was made at two-thirds of this distance. A line perpendicular to the thigh's central axis was drawn to meet the horizontal line. The subjects were then asked to sit upright on the edge of a couch, with arms hanging by their side. The dominant leg bent at a 90° angle at the knee. The measurer stood facing the subject's dominant side, on the lateral thigh.

To measure the skinfold, the skin at the designated site was lifted using the thumb and index finger. Simultaneously, the leg was extended with the heel placed firmly on the floor.

BF

The subject lay prone with both knees extended. The measurer stood facing the subject's dominant side, on the lateral thigh. The distance between the ischial tuberosity and the midpoint of the lateral patella was measured. A small horizontal point was placed at the center point. A perpendicular line was drawn from the centerline of the thigh to meet the horizontal line. To measure skinfold, the marked site was grasped using the index and thumb finger while ensuring knee was bent at a 90-degree angle.

3.2.4. Assessment of isokinetic testing with NIRS technology

Two different types of contractions, such as CON and ECC, were conducted on the quadriceps and hamstring muscles. This was done using an isokinetic system called Cybex NORM® by Humac CA, USA. Prior to the assessment, subjects engaged in a 5-minute warm-up session on a bicycle ergometer. Subsequently, they were positioned on the isokinetic dynamometer, adhering to the guidelines provided by the manufacturer for proper alignment and stability [155-157].

The evaluation comprised two parts: assessing the quadriceps muscles in a seated position and evaluating the hamstring muscles in a prone position. Evaluation protocols were programmed into the computer software prior to testing.

During the testing session, Train.Red sensors were placed on the participants' dominant leg, specifically targeting the VL and BF, utilizing a specially designed adaptable band. This band, made of pliable material, included four silicone strips with anti-slip properties to ensure stability on the limb and avoid any slippage. The positioning for both muscles was established according to findings from an Electromyography study conducted by Scott Cocking.

Quadriceps muscle:

The dynamometer calibration was adjusted as per the manufacturer's guidelines. During quadriceps contraction, participants were fastened to the chair using a belt while seated. They were then instructed to grasp the sides of the dynamometer chair manually [158]. To avoid compensatory movements, the pelvis and thorax were firmly supported and stabilized.

A belt was placed on the thigh. It was positioned 3 cm above the attachment point of the quadriceps-patella tendon [156]. Additionally, the rotation axis of the dynamometer was aligned. This alignment was ensured with the axis of the femoral joint [157].

Ankle pads were positioned. They were located around two finger-widths above the lateral malleolus [159]. Furthermore, they were modified to accommodate the participant's comfort level. The extent of knee movement, i.e., range of motion was established. It was set from a flexed position of 90 degrees to an extended position of 0 degrees for CON contractions and from 90° to 10° for ECC contractions [158, 160]. In all tests, the 'gravity compensation' function was enabled to offset the gravitational force exerted by the weight of the limb [158].

To target the VL portion of the quadriceps muscle, the NIRS sensor was positioned at a distance of two-thirds along the path from the anterior superior iliac spine to the superior-lateral edge of the patella. The quadriceps muscle was assessed through a sequence of tests at different speeds. Initially, 5 repetitions were performed at a velocity of 60 degrees per second (60°/s), which is considered slow, for maximal CON contraction. This was followed by 10 repetitions at a moderate velocity of 180 degrees per second (180°/s), and subsequently, 15 repetitions at a high velocity of 300 degrees per second (300°/s) [78]. Afterward, 5 repetitions at a speed of 60°/s were performed for maximal ECC contraction. Subsequently, ECC contractions were carried out at 60°/s for the same muscle group.

Hamstring muscle

For isokinetic assessments of the hamstring muscle, dynamometer calibration was adhered to the manufacturer's guidelines. Adjustments were made above the pelvis and knee to minimize unnecessary muscle recruitment and focus movement on the knee joint [161]. In

the prone position, the pelvis was secured with a belt, aligning the hip at 180 degrees. The rotation axis of the dynamometer was aligned with the axis of the femoral joint [161].

An ankle pad was positioned approximately 3 cm above the medial malleolus, accommodating the participant's foot comfortably [162]. The range of motion were set from 0° knee extension (starting position) to 90° knee flexion (maximum voluntary 0° for each participant) for CON contractions and from 90° to 10° for ECC contractions [163]. The function for compensating gravitational effects was activated [164, 165].

For BF part of Hamstring muscle, NIRS sensor was placed at the midpoint distance from the ischial tuberosity to the midpoint of the lateral patella.

The hamstring muscles underwent evaluation through a series of testing. This included performing maximal CON contractions with 5 repetitions at 60°/s (low-speed), followed by 10 repetitions at 180°/s (medium-speed), and then 15 repetitions at 300° (high-speed) [155,165]. Additionally, maximal ECC contractions were performed, consisting of 5 repetitions at 60°/s.

Prior to commencing the evaluation at each velocity, participants performed three practice repetitions. These repetitions were performed at submaximal intensity, equivalent to 50% of their self-perceived effort [166]. This allowed participants to familiarize themselves with the procedure and effectively warm up. A 30-second break was given during the intervals between submaximal attempts. Additionally, a 1-minute rest period was provided between each testing speed. Verbal instructions were provided to participants before each assessment [167]. These instructions were standardized and emphasized the need to exert maximal effort [168]. Participants were instructed to maintain this effort throughout the entire range of motion. A 10-minute rest period was given between the two positions to reduce musculoskeletal fatigue [169]. Peak torque at each repetition for each isokinetic angular velocity was recorded in Nm/kg.



Image 3.2. Assessment of isokinetic testing

In this study, we used the Train.Red NIRS device. In this device, the distance between the transmitter and receiver, known as interpod spacing, was measured at 35 mm. Consequently, the penetration depth was calculated to be about half of this distance. This equated to 17.5 mm in total. All participants included in this study had subcutaneous fat thickness below 17.5mm at the location of the NIRS device.

The sensor was linked to a smartphone app. This allowed for the collection and transfer of data. The data was sampled at a rate of 10Hz. The device operated based on the modified Beer-Lambert law to determine the absolute levels of O_2Hb , HHb , SmO_2 , and tHb .



Image 3.3. Assessment of isokinetic testing with NIRS technology



4. RESULTS

4.1. Demographic Characteristics

The study found no difference in age, and BMI between the elite volleyball athletes and healthy sedentary individuals ($p > 0.05$, Table 4.1).

Table 4.1. Participants demographic characteristics

		Volleyball Athletes (n=17) (Mean and SD)	Healthy Sedentary (n=14) (Mean and SD)	p
Age (years)		17.53±1.50	18.21 ± 1.57	0.227
BMI (kg /m ²)		22.9±1.7	23.2 ± 4.0	0.825
		n (%)	n (%)	
Gender	Male	17 (54.8%)	14 (45.2%)	
	Female	0	0	
Lower Extremity Dominance	Right	16 (94.1%)	10 (71.4%)	
	Left	1 (5.9%)	4 (28.6%)	

BMI: Body mass index

The ATT of the participants in the elite athletes and healthy sedentary group is shown in table 1.2. A statistically significant variance was observed among the groups regarding ATT.

Table 4.2. Comparison of dominant leg's adipose tissue thickness of the athletes and healthy sedentary group

		Volleyball Athletes (n=17) (Mean and SD)	Healthy Sedentary (n=14) (Mean and SD)	p
Dominant Lower Extremity ATT	Quadriceps	4.16±1.44	8.67±2.45	<0.001
	Hamstring	2.01±0.39	9.55±2.28	<0.001

ATT: Adipose tissue thickness

4.2. Effect of Isokinetic Speeds During CON Contractions of VL Muscle:

A repeated measures analysis of variance (ANOVA) was performed to evaluate the effects of both speed and muscle action modes on SmO₂, Hb Diff, tHb, and O₂Hb.

There was no Speed x Group interaction for the SmO₂, Hb Diff, tHb, and O₂Hb during CON contraction at 60, 180 and 300 °/sec speed. Although there was no Speed x Group interaction, there was a statistical difference between the groups in terms of tHb, O₂Hb and HHb (Table

2.1). These total blood flow measures of volleyball athletes were higher than those of sedentary individuals.

The speed main effect was statistically significant. Significant differences were observed in terms of SmO₂, Hb Diff, tHb, and O₂Hb between speeds. However, no statistically significant difference was found among the speeds in terms of HHb. The post hoc test results showed that, SmO₂ during 300°/sec was statistically higher than 180°/sec ($p=0.023$). The Hb Diff levels at a speed of 60°/sec exhibited a notable decrease in comparison to both 180°/sec ($p = 0.003$) and 300°/sec ($p < 0.001$), respectively. Additionally, Hb Diff at 180°/sec was found to be lower than at speed 300°/sec ($p < 0.001$). The tHb at 300°/sec resulted in significantly higher levels compared to 60°/sec ($p < 0.001$) and 180°/sec ($p = 0.007$). O₂Hb levels at 300°/sec exhibited a notably higher significance when compared with both 60°/sec ($p < 0.001$) and 180°/sec ($p < 0.001$). Conversely, there was no statistical difference in O₂Hb between 60°/sec and 180°/sec ($p = 0.289$).

The statistical findings for SmO₂, Hb Diff, tHb, O₂Hb, and HHb are presented in the table below for both groups.

Table 4.3. Effect of Isokinetic speeds during CON contractions of VL Muscle in volleyball athletes and healthy sedentary individuals:

		60°/sec	180°/sec	300°/sec	Group * Speed F p η^2	Group F p η^2	Speed F p η^2
SmO ₂ (%)	Volleyball Athletes	63.15±11.83	62.37±11.55	63.53±11.09	0.960 0.395 0.064	0.203 0.656 0.007	4.427 0.021 0.240
	Sedentary	63.69±8.03	63.30±7.75	66.69±7.40			
Hb Diff (μM)	Volleyball Athletes	23.91±6.52	24.73±5.42	26.98±4.52	0.973 0.390 0.065	2.786 0.088 0.197	17.592 <0.001 0.557
	Sedentary	20.37±4.02	22.23±4.14	24.45±4.46			
tHb (μM)	Volleyball Athletes	138.30±17.05	139.09±18.01	141.70±20.13	0.949 0.393 0.032	9.170 0.005 0.240	9.809 <0.001 0.253
	Sedentary	116.33±22.28	117.58±22.53	118.49±23.15			
O ₂ Hb (μM)	Volleyball Athletes	81.30±8.42	81.78±8.32	84.24±10.05	0.585 0.561 0.020	10.776 0.003* 0.271	16.879 <0.001 0.368
	Sedentary	68.33±12.24	69.87±12.58	71.41±12.90			
HHb (μM)	Volleyball Athletes	57.00±10.03	57.31±10.38	57.46±10.57	1.636 0.214 0.104	6.757 0.015 0.189	0.424 0.659 0.029
	Sedentary	48.00±10.32	47.70±10.19	47.07±10.55			

$p < 0.05$, SmO_2 : Muscle oxygen saturation, Hb Diff: Hemoglobin difference, tHb: Total hemoglobin, O_2Hb : Oxygenated hemoglobin, HHb: Deoxygenated hemoglobin, %: Percentage, μM : micromolar, η^2 : Effect size

Values are given as mean and standard deviation.

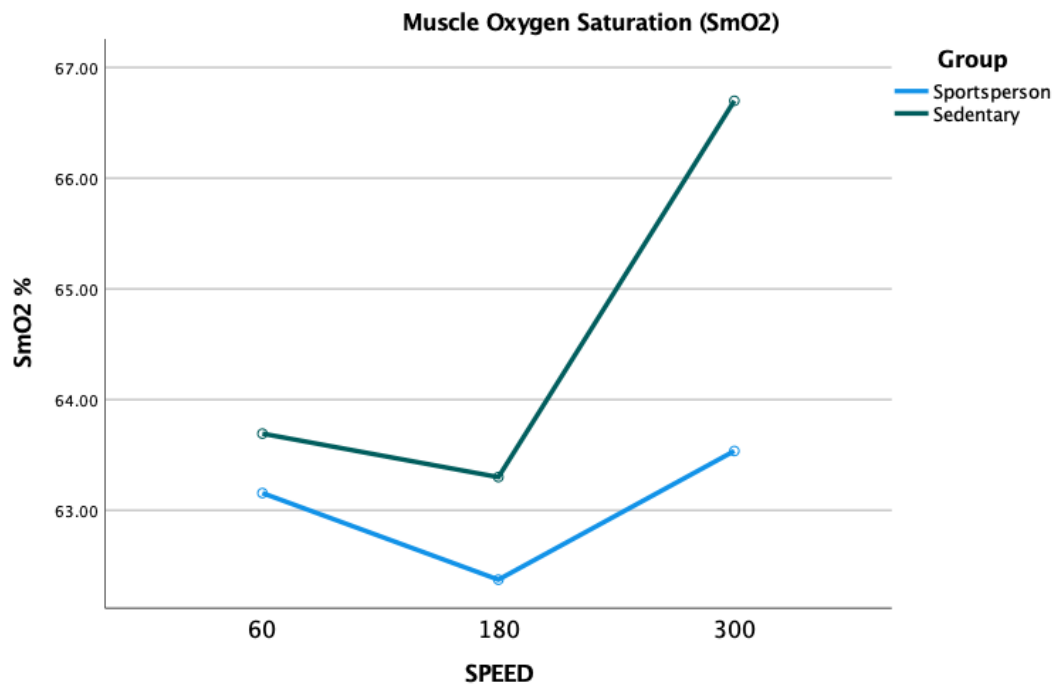


Figure 4.1. Comparison of volleyball athletes and healthy sedentary individuals during CON contractions of VL in terms of SmO_2 in different isokinetic speeds.

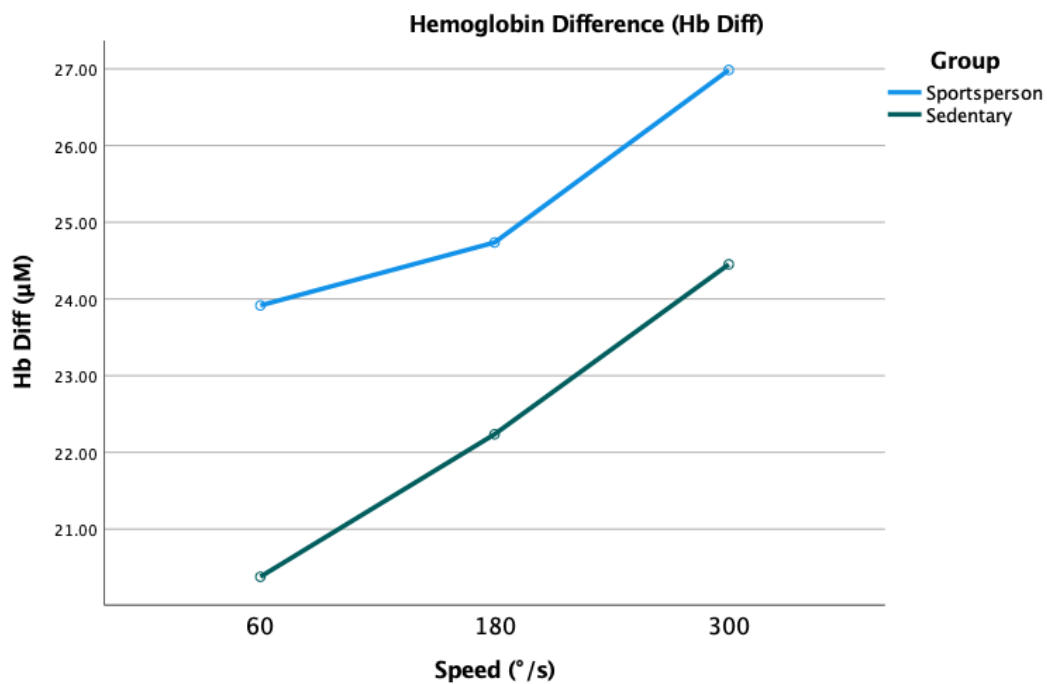


Figure 4.2. Comparison of volleyball athletes and healthy sedentary individuals during CON contractions of VL in terms of Hb Diff in different isokinetic speeds.

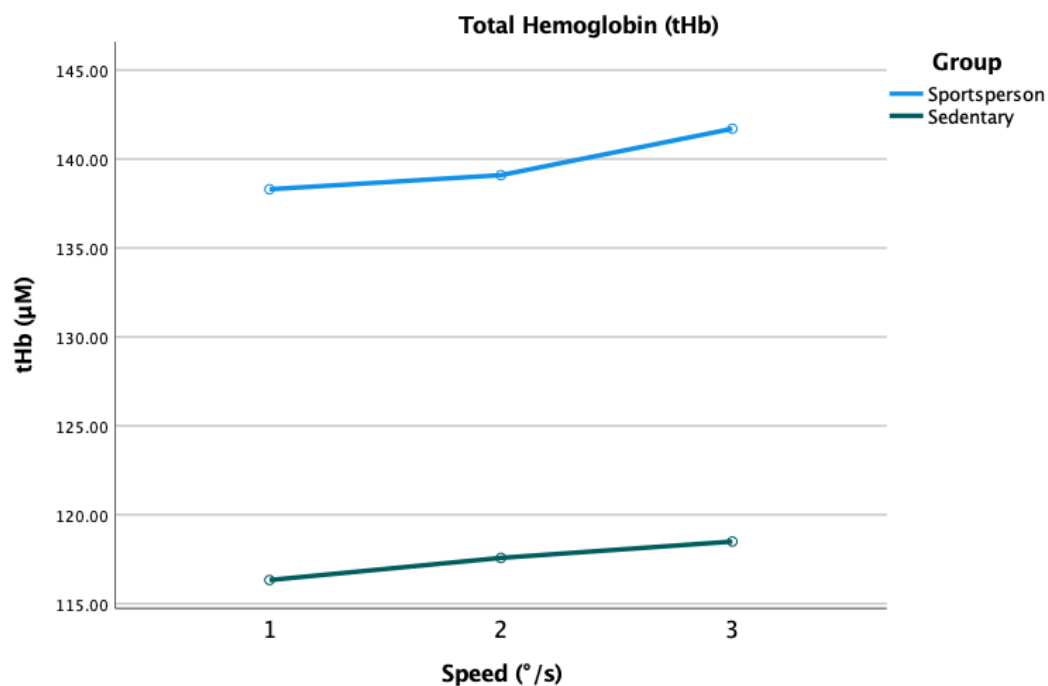


Figure 4.3. Comparison of volleyball athletes and healthy sedentary individuals during CON contractions of VL in terms of tHb in different isokinetic speeds.

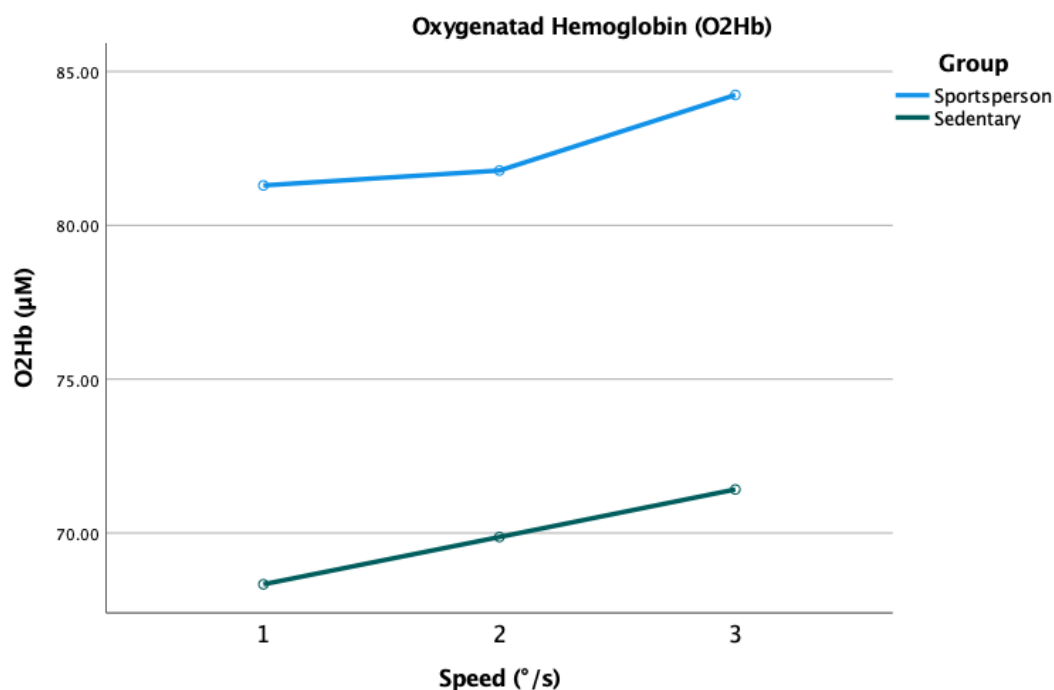


Figure 4.4. Comparison of volleyball athletes and healthy sedentary individuals during CON contractions of VL in terms of O₂Hb in different isokinetic speeds.

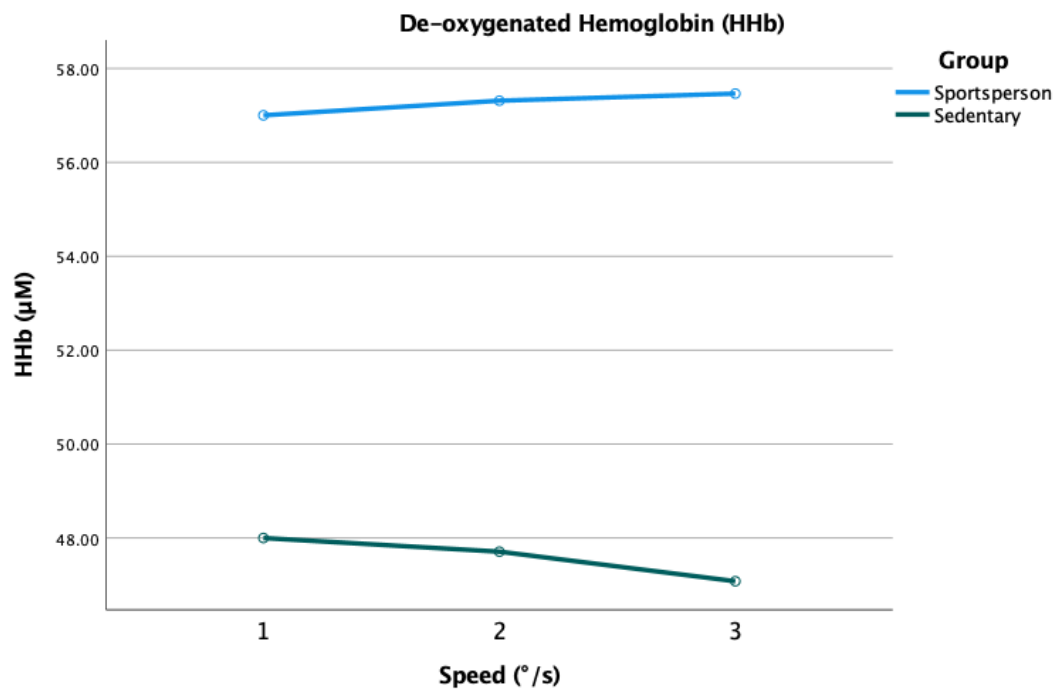


Figure 4.5. Comparison of volleyball athletes and healthy sedentary individuals during CON contractions of VL in terms of HHb in different isokinetic speeds.

4.3. Effect of Isokinetic Speeds during CON Contractions of BF Muscle:

There was no Speed x Group interaction for the SmO₂, Hb Diff, tHb, O₂Hb and HHb during varying speeds. At the same time, the group main effect was not statistically significant in terms of SmO₂, Hb Diff, tHb, O₂Hb and HHb.

The speed main effect was significant in terms of SmO₂ and Hb Diff. Hb Diff was found to be significantly greater during 300°/sec compared to 60°/sec, ($p = 0.008$). Nevertheless, there were no statistically significant differences found between 60 and 180°/sec ($p = 0.102$), as well as between 180 and 300°/sec ($p = 0.131$). The overall speed effect on SmO₂ was statistically significant, but subsequent pairwise comparisons (post-hoc tests) do not reveal any specific differences between conditions. The statistical findings are presented in the table below for BF muscle.

Table 4.4. Effect of Isokinetic speeds during CON contractions of BF Muscle in volleyball athletes and healthy sedentary individuals:

		60°/sec	180°/sec	300°/sec	Group * Speed F p η^2	Group F p η^2	Speed F p η^2
SmO ₂ (%)	Volleyball Athletes	67.16±9.47	69.24±10.05	68.38±10.82	0.594 0.541 0.021	0.326 0.572 0.012	4.215 0.023 0.131
	Sedentary	69.06±5.79	70.26±6.11	70.73±5.61			
Hb Diff (μ M)	Volleyball Athletes	22.26±5.32	23.47±4.06	25.02±4.94	0.502 0.608 0.018	0.608 0.442 0.021	7.591 0.001 0.213
	Sedentary	24.31±6.92	25.23±6.66	25.97±6.99			
tHb (μ M)	Volleyball Athletes	125.70±19.84	125.94±20.20	131.30±22.44	1.423 0.249 0.048	2.506 0.125 0.082	1.182 0.314 0.041
	Sedentary	116.58±22.18	115.21±21.73	115.67±21.21			
O ₂ Hb (μ M)	Volleyball Athletes	73.95±10.51	74.64±10.34	77.85±11.16	1.453 0.243 0.049	1.342 0.256 0.046	2.402 0.100 0.079
	Sedentary	70.44±14.21	70.17±13.89	70.80±13.82			
HHb (μ M)	Volleyball Athletes	51.74±10.02	51.30±10.26	53.45±11.66	1.194 0.305 0.041	4.155 0.051 0.129	0.533 0.558 0.019
	Sedentary	46.14±8.24	45.03±8.05	44.87±7.62			

$p < 0.05$, SmO₂: Muscle oxygen saturation, Hb Diff: Hemoglobin difference, tHb: Total hemoglobin, O₂Hb: Oxygenated hemoglobin, HHb: Deoxygenated hemoglobin, %: Percentage, μ M: micromolar, η^2 : Effect size

Values are given as mean and standard deviation.

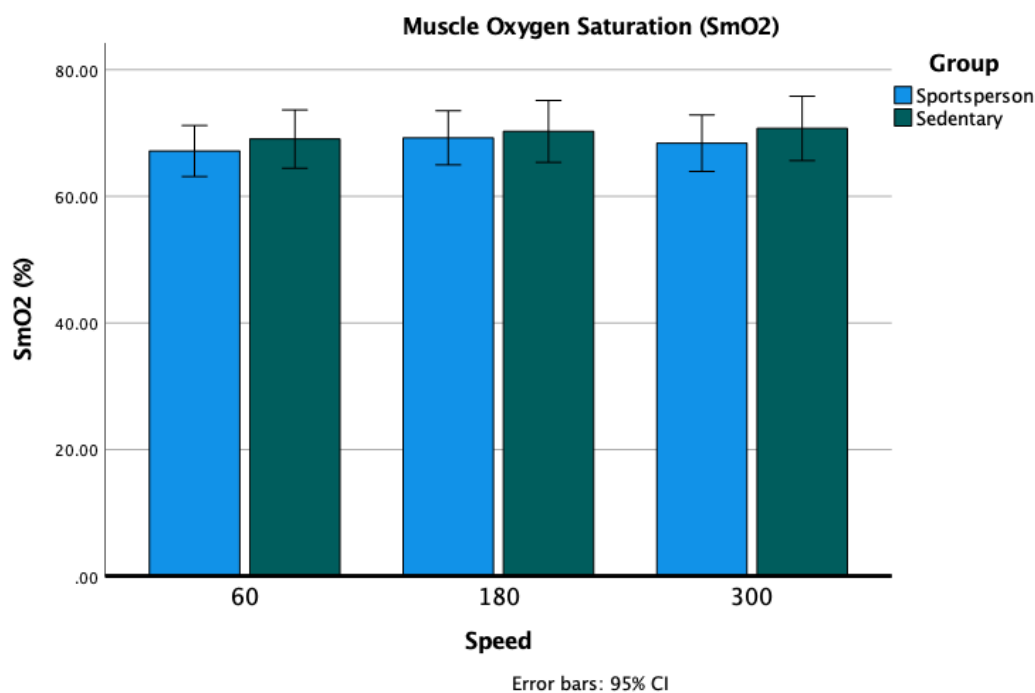


Figure 4.6. Comparison of volleyball athletes and healthy sedentary individuals during CON contractions of BF in terms of SmO₂ in different isokinetic speeds.

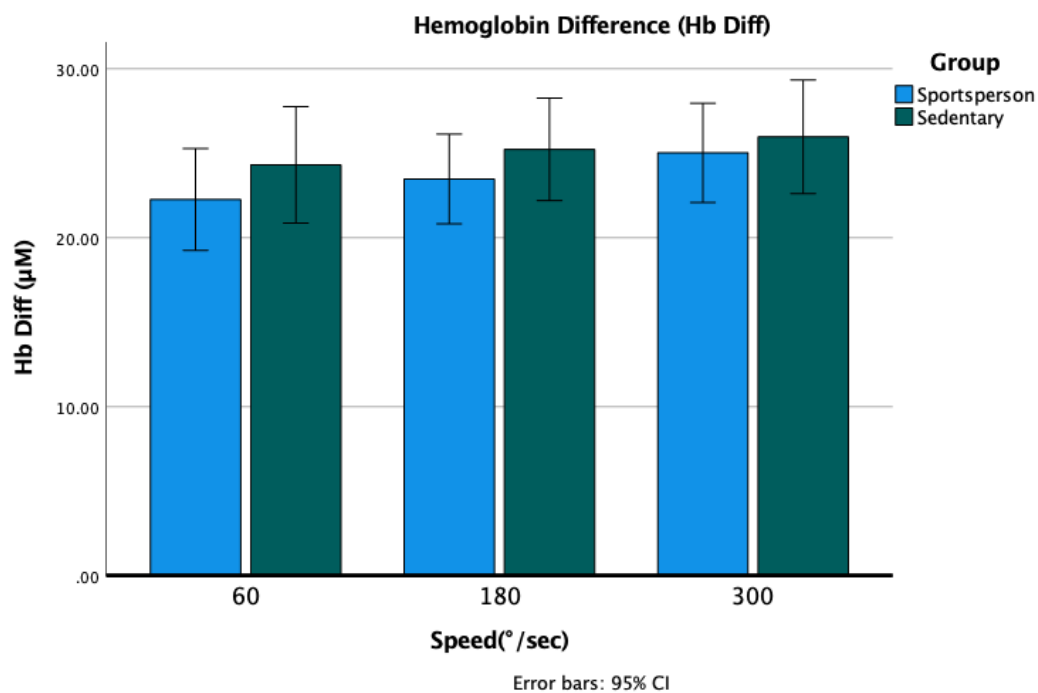


Figure 4.7. Comparison of volleyball athletes and healthy sedentary individuals during CON contractions of BF in terms of Hb Diff in different isokinetic speeds.

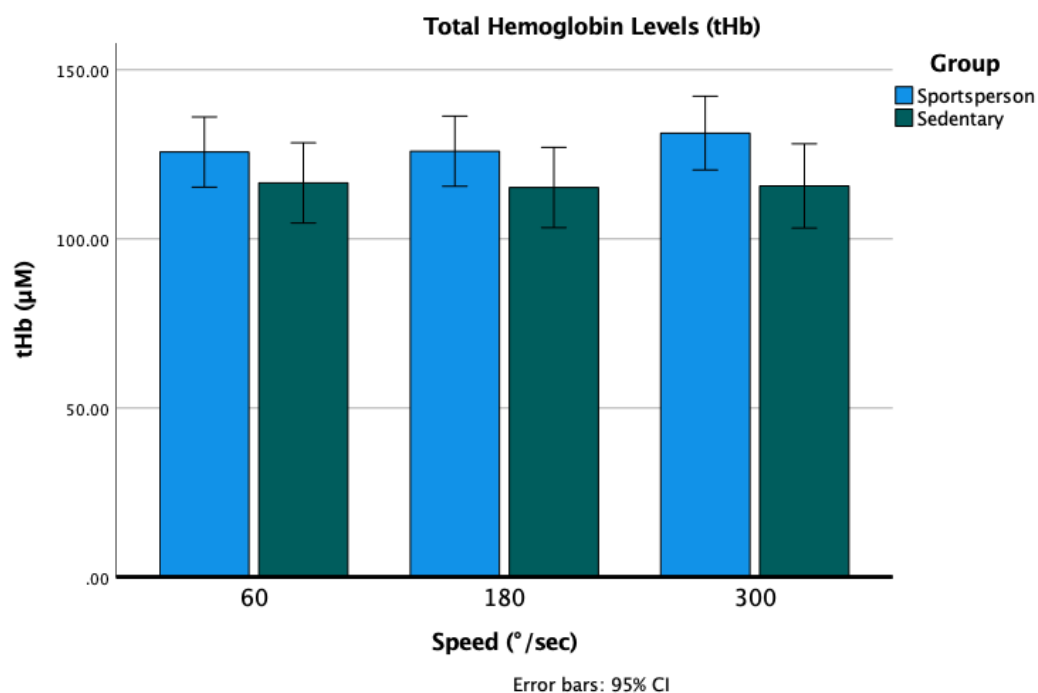


Figure 4.8. Comparison of volleyball athletes and healthy sedentary individuals during CON contractions of BF in terms of tHb in different isokinetic speeds.

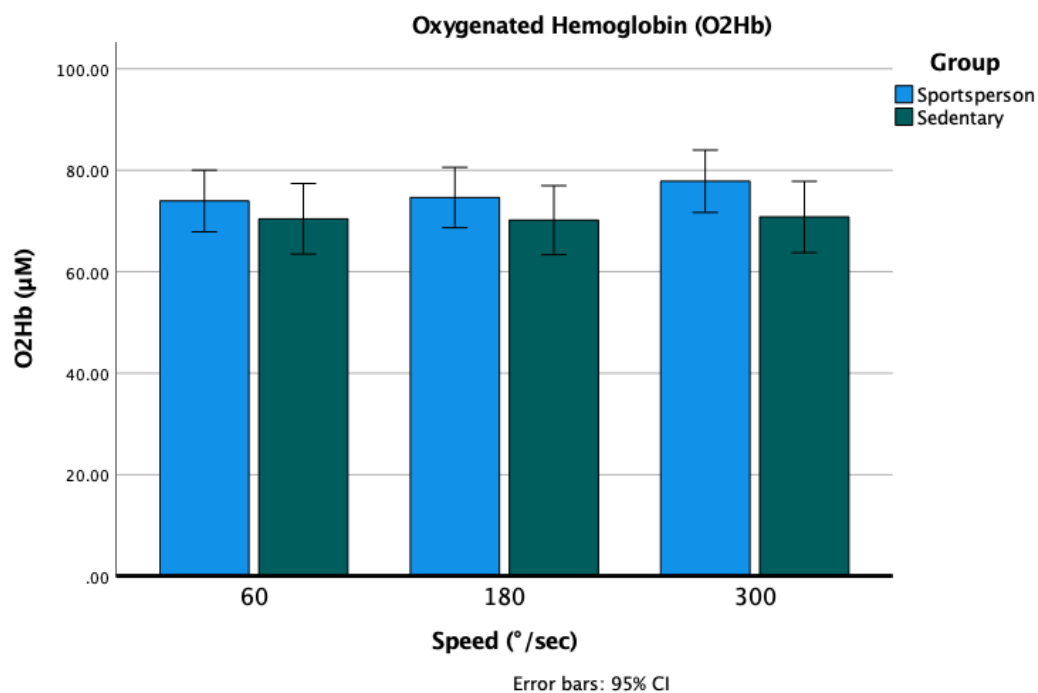


Figure 4.9. Comparison of volleyball athletes and healthy sedentary individuals during CON contractions of BF in terms of O₂Hb in different isokinetic speeds.

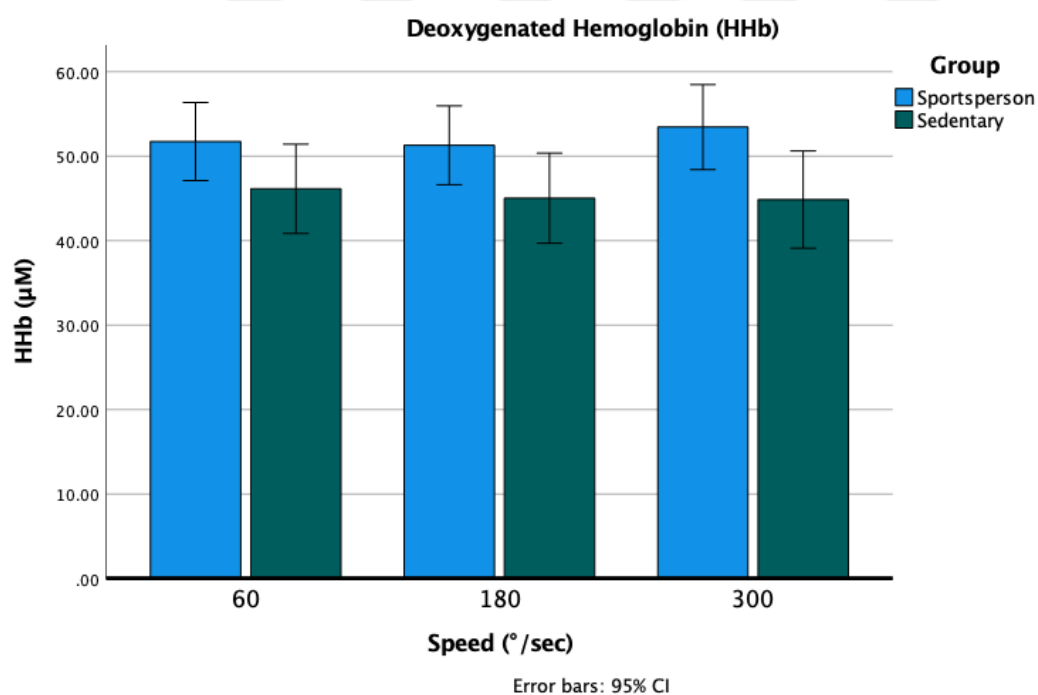


Figure 4.10. Comparison of volleyball athletes and healthy sedentary individuals during CON contractions of BF in terms of HHb in different isokinetic speeds.

4.4. Effect of Isokinetic Speeds during CON/ECC Contractions of VL Muscle:

There was no Exercise x Group interaction for SmO₂, Hb Diff, tHb, O₂Hb and HHb during CON and ECC 60°/sec (Table 4.4.) Despite the absence of a Speed x Group interaction, a statistically significant main effect was observed for the group. Notably, there was a difference between the groups in terms of the Hb Diff, tHb, O₂Hb and HHb. Total blood flow measures of volleyball athletes were higher than sedentary individuals.

The speed main effect was statistically significant. Significant differences were observed in terms of activation of the Hb Diff, tHb, O₂Hb between speeds. However, no statistical difference was observed among the speeds in terms of HHb. According to the pairwise comparison, Hb Diff, tHb, O₂Hb was higher in CON at 60°/sec than in ECC at 60°/sec.

Table 4.5. Effect of isokinetic speeds during CON/ECC contractions of VL muscle in volleyball athletes and healthy sedentary individuals:

		60°/sec CON	60°/sec ECC	Group * Speed F p η ²	Group F p η ²	Speed F p η ²
SmO ₂ (%)	Volleyball Athletes	63.15±11.83	63.60±9.19	1,317 0.261 0.043	0.677 0.417 0.023	2.037 0.164 0.066
	Sedentary	63.69±8.03	67.81±5.61			
Hb Diff (μM)	Volleyball Athletes	23.91±6.52	29.97±5.06	0.212 0.649 0.007	4.536 0.042 0.135	97.420 <0.001 0.771
	Sedentary	20.37±4.02	25.89±4.58			
tHb (μM)	Volleyball Athletes	138.30±17.05	143.43±18.21	0.103 0.750 0.004	9.520 0.004 0.247	27.307 <0.001 0.485
	Sedentary	116.33±22.28	120.87±23.45			
O ₂ Hb (μM)	Volleyball Athletes	81.30±8.42	86.65±9.13	0.636 0.537 0.043	11.838 0.002 0.290	19.136 <0.001 0.577
	Sedentary	68.33±12.24	73.36±13.42			
HHb (μM)	Volleyball Athletes	57.00±10.03	56.78±9.77	0.201 0.658 0.007	6.348 0.018 0.180	1.453 0.238 0.048
	Sedentary	48.00±10.32	47.51±10.25			

$p < 0.05$, SmO₂: Muscle oxygen saturation, Hb Diff: Hemoglobin difference, tHb: Total hemoglobin, O₂Hb: Oxygenated hemoglobin, HHb: Deoxygenated hemoglobin, %: Percentage, μM: micromolar, η²: Effect size

Values are given as mean and standard deviation.

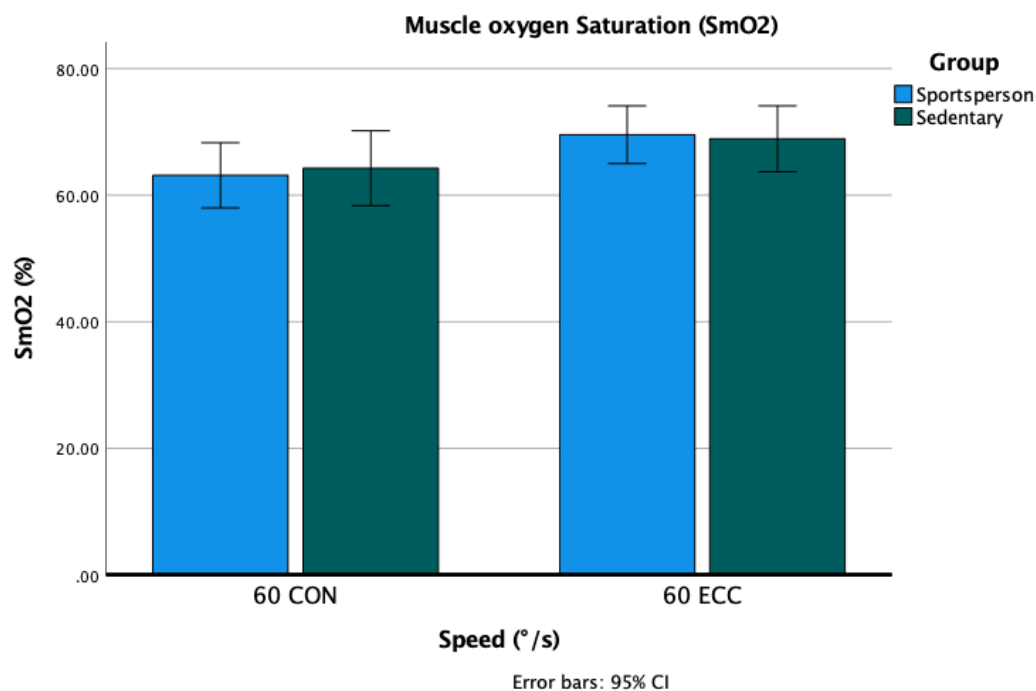


Figure 4.11. Comparison of volleyball athletes and healthy sedentary individuals during CON/ECC contractions of VL in terms of SmO₂ in different isokinetic speeds.

4.5. Effect of Isokinetic Speeds during CON/ECC Testing of BF Muscle:

During CON and ECC 60°/sec there was Speed x Group interaction for the Hb Diff only. The Hb Difference was found to be higher for volleyball athletes (<0.001) during CON and ECC. Although there was Speed x Group interaction for the Hb Diff, the group main effect was found not to be statistically significant.

The speed main effect was statistically significant. Significant differences were observed in terms of the Hb Diff and O₂Hb between speeds. Nonetheless, there was no statistically notable differences detected among the speeds concerning SmO₂, tHb and HHb. According to the post hoc test results, Hb Diff and O₂Hb in the 60°/sec ECC was statistically higher than in the speed CON 60°/sec (p<0.001). Table 4.5. shown below:

Table 4.6. Effect of isokinetic speeds during CON/ECC contractions of BF muscle in volleyball athletes and healthy sedentary individuals:

		Group *	Group	Speed
60°/sec CON	60°/sec ECC	Speed F p η ²	F p η ²	F p η ²

SmO ₂ (%)	Volleyball Athletes	67.16±9.47	69.57±10.87	0.581 0.452 0.020	0.053 0.819 0.002	0.471 0.498 0.017
	Sedentary	69.06±5.79	68.93±6.18			
Hb Diff (μM)	Volleyball Athletes	22.26±5.32	30.74±4.32	6.418 0.017 0.186	0.015 0.903 0.001	48.066 <0.001 0.632
	Sedentary	24.31±6.92	28.25±5.69			
tHb (μM)	Volleyball Athletes	125.70±19.84	129.84±19.09	1.077 0.355 0.074	1.587 0.218 0.054	0.904 0.417 0.063
	Sedentary	116.58±22.18	120.39±20.98			
O ₂ Hb (μM)	Volleyball Athletes	73.95±10.51	80.28±11.00	1.602 0.216 0.054	1.202 0.282 0.041	28.029 <0.001 0.500
	Sedentary	70.44±14.21	74.32±12.75			
HHb (μM)	Volleyball Athletes	51.74±10.02	49.56±8.39	1.905 0.178 0.064	2.033 0.165 0.068	2.172 0.152 0.072
	Sedentary	46.14±8.24	46.07±8.59			

$p < 0.05$, SmO₂: Muscle oxygen saturation, Hb Diff: Hemoglobin difference, tHb: Total hemoglobin, O₂Hb: Oxygenated hemoglobin, HHb: Deoxygenated hemoglobin, %: Percentage, μM: micromolar, η^2 : Effect size

Values are given as mean and standard deviation.

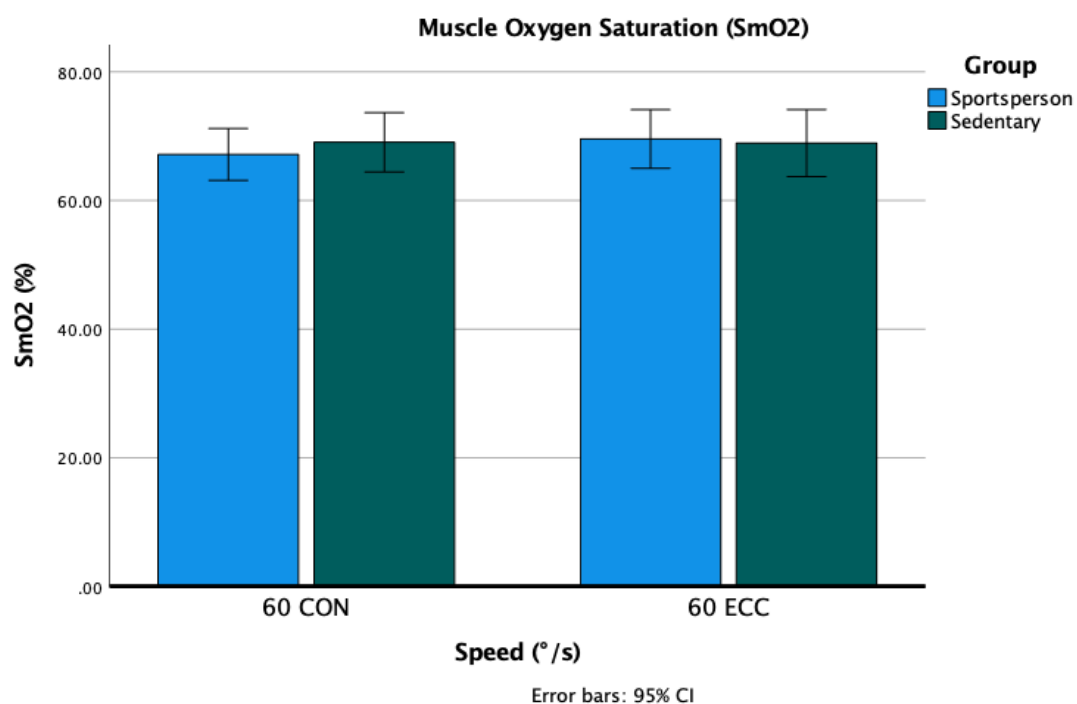


Figure 4.12. Comparison of volleyball athletes and healthy sedentary individuals during CON/ECC contractions of BF in terms of SmO₂ in different isokinetic speeds.



5. DISCUSSION

This study was designed to investigate potential differences in SmO_2 and tHb within the VL, as well as in, BF muscle, between sedentary individuals and athletes during isokinetic maximal CON and ECC contractions executed at varying speeds. According to our results, in the VL CON contractions, SmO_2 , tHb and O_2Hb levels at a velocity of $300^\circ/\text{sec}$ were significantly ($p < 0.05$) greater compared to those recorded at $60^\circ/\text{sec}$ and $180^\circ/\text{sec}$, while HHb values did not show any differences ($p > 0.05$) among the speeds. In the BF CON contractions, only the Hb Diff was found to be significantly ($p < 0.05$) greater during $300^\circ/\text{sec}$ compared to $60^\circ/\text{sec}$. In the VL, Hb Diff , tHb , O_2Hb were higher ($p < 0.05$) in CON than in ECC at $60^\circ/\text{sec}$., while HHb values did not show any differences. In the BF, Hb Diff and O_2Hb in the ECC were statistically higher than in the CON at $60^\circ/\text{sec}$ ($p < 0.05$). In the VL, volleyball athletes had higher total blood flow measures than sedentary individuals, while no group differences were found in the BF.

Muscle oxygenation depends on the intensity of the activity, as well as the mode of muscle action [170,171]. In slow-velocity isokinetic muscle actions, there is recruitment of both slow-twitch (type I) and fast-twitch (type II) muscle fibers, while at high velocity, a reduced number of fibers are engaged, particularly type I fibers [172,173]. Studies have indicated that there is increased muscle activity during slow-velocity isokinetic exercise as opposed to exercises conducted at high velocity [172,174,175]. Increased intramuscular pressure is noted when the angular velocity is at its slowest, coinciding with the peak torque, which may compress arteries and veins [176]. This compression, coupled with the heightened energy expenditure at slow angular pace, contributes to a reduction in tissue oxygen saturation.

Similar results were reported in a study conducted by Denis, Wilkinson, and De Vito (2011), where the authors explored the impact of angular velocity on the oxygen levels within the VL and rectus femoris muscles. Eleven male individuals who were recreationally active performed ten knee extensions executed at maximum effort at velocities of 30, 60, and $120^\circ/\text{sec}$ [177].

Tissue oxygenation index (TOI) and tHb were measured in those muscles using NIRS. The results revealed a significant decrease in both muscles TOI at $300^\circ/\text{sec}$ compared to

velocities of 60°, 120°, and 240°/sec. Moreover, reported that, the level of SmO₂ rose proportionally with the angular velocity. This implies that during high angular velocity movements, oxygen was retained within the blood vessels due to fewer muscle fibers being engaged. Conversely, during slow angular velocity exercises, the muscles exhibited an increased oxygen demand, and it was utilized by tissue lead to reduction in SmO₂. This result is in line with our study. But they additionally reported an inverse relationship with tHb and velocity. However, in our study we found an increase in tHb with higher velocity. We believe that these differences may be attributed to the varying velocities utilized in their study compared to those used in our study.

SmO₂, depicting the dynamic equilibrium between oxygen delivery and utilization and tHb, signifying the volume of local blood [178]. The derived variables measures are the levels of O₂Hb, representing the supply of oxygen, HHb, indicating oxygen extraction [179-181]. Researchers have stated that elevated HbO₂ and lowered HHb levels signify oxygen availability, whereas decreased HbO₂ and heightened HHb levels indicate oxygen consumption within the local muscle [182].

In our study, CON measurements from the VL muscle revealed that SmO₂ and tHb levels at a speed of 300°/sec were substantially greater compared to those recorded at 60°/sec and 180°/sec. Additionally, O₂Hb concentrations at 300°/sec were significantly elevated relative to the lower velocities, while HHb values did not show any significant variance among the speeds.

The study conducted by Kime et al. (2005), aligns with our observations [183]. They explored the dynamics of tHb during fixed-load cycling exercises. Seven participants underwent cycling exercises at intensities ranging from 20% to 100% of their maximum work rates for periods of 5 minutes each. The changes in ΔO₂Hb and ΔtHb in the right VL were tracked via a NIRS. Results showed that at workloads up to 60% W_{max}, following an initial drop at the beginning, both ΔtHb and ΔO₂Hb gradually rose until the conclusion of the activity. A significant positive correlation emerged between ΔtHb and ΔO₂Hb. The reason they explained is that enhanced muscle oxygenation during cycling up to 60% work rate max could stem from an increase in oxygen delivery linked to exercise-induced expansion of blood volume. Above these work rates, the halt in ΔtHb growth during more

intense exercise may result in decreased oxygenation of muscle tissues and an accumulation of lactate.

According to Quaresima and Ferrari (2020) HHb can act as a marker of O₂ utilization when tHb levels are constant [184]. During stationary cycling exercises, there was a noticeable increase in tHb. Studies mentioned that this rise in tHb may be attributed to exercise-induced hyperemia. Taking this into account, Kime et al. (2013) explored how changes in skin blood flow could influence tHb during similar cycling activities [185].

In research conducted by Kime et al. (2013) changes in tHb were examined during constant rate cycling exercises [185]. This study involved ten healthy males who engaged in 6-minute cycling sessions at both moderate and intense workloads. Measurements of O₂Hb, HHb, tHb, and SmO₂ were taken using NIRS from the VL muscle. At moderate exercise levels, there were continual increases in tHb, O₂Hb, and SmO₂ until the exercise concluded. However, HHb levels remained constant at moderate work rates, which corroborates our results. It was noted that tHb] did not show significant differences between the various work rates, whereas O₂Hb was significantly elevated during moderate compared to intense exercise. The explanation provided was that at higher work rates, muscle oxygen consumption may surpass the muscle's oxygen supply, leading to a greater degree of deoxygenation due to an imbalance in the dynamic oxygen equilibrium.

In VL, our findings suggest that at a speed of 300°/sec, both tHb and O₂Hb levels were notably higher compared to speeds of 180°/sec and 60°/sec, with no discernible difference in HHb. One of the possible explanations for this increased tHb and O₂Hb at high speed is the rapid rhythmic compression and relaxation of blood vessels by muscle contractions act as a "muscle pump," aiding venous return and facilitating the circulation of blood back to the heart. This muscle pump effect helps maintain cardiac output and systemic circulation during high-velocity exercise, supporting overall cardiovascular function and maintaining central venous pressure.

An alternate explanation is that during physical activity, the sympathetic nervous system increases cardiac output and redistributes blood flow. This occurs as heightened sympathetic nerve activity prompts the release of norepinephrine, which binds to α -adrenergic receptors on vascular smooth muscle. Consequently, there's vasoconstriction in less active tissues like

splanchnic organs, skin, and adipose tissue. The degree of vasoconstriction depends on factors such as autonomic innervation, receptor density, and sympathetic outflow, as a result, the degree of vasoconstriction is specific to each tissue, leading to distinct responses in the skin, muscle, and viscera. Collectively, this process directs blood flow towards metabolically active tissues.

At higher intensity exercise, there may be lower SmO_2 , higher lactate accumulation, and increased HHb [186]. Recent studies have highlighted the instability of tHb during constant exercise, posing challenges in interpreting changes in HHb levels. Our findings corroborate this notion, as the lack of significant variance in HHb among varying exercise speeds suggests that HHb may not adequately reflect alterations in muscle oxygen extraction. We found decreased SmO_2 in our study, while HHb remained relatively stable. The above explanation could be potential reason of stable HHb even with the reduced SmO_2 observed in our study.

A study conducted by Pethick, Winter, and Burnley (2019) investigated the relationship between the metabolic rate of a system and the complexity of fluctuations in its output [187]. Thirteen individuals performed intermittent isometric knee extensor contractions at different intensities, following a 60% duty cycle (6 seconds of contraction, followed by 4 seconds of rest), either until they couldn't continue or for a duration of 30 minutes. Muscle metabolic rate showed a significant increase after 2 minutes at 40% of maximal voluntary contraction, but not at 20%. The results indicated a negative relationship between muscle torque complexity and metabolic rate during high-intensity contractions. The author inferred that the complexity of a system is partly influenced by its metabolic rate.

In recent systematic research by Orcioli-Silva et al. (2023), the literature has extensively explored NIRS parameters during cycling, treadmill exercises, knee extension, isometric biceps brachii contractions, and swimming routines [186]. However, there's a notable scarcity of studies focusing on the Hamstring muscle. Sixteen studies have investigated HHb, while 13 studies have delved into HbO_2 , 12 analyses on tHb, with 8 studies scrutinizing TSI, 2 studies examining Hb Diff, and another 2 studies exploring cerebral and muscle blood volume and oxygenation. Only one study has scrutinized oxygen extraction as an outcome for both cerebral and muscular measurements. Due to this significant gap in available data concerning the BF muscle, our study marks the first attempt to analyze both VL of

quadriceps and BF of hamstring muscles under isokinetic CON and ECC contractions at varying speeds.

For BF, in our study, Hb Diff was found to be significantly greater during 300°/sec compared to 60°/sec, ($p = 0.008$) and there was the overall effect found in SmO₂ but subsequent pairwise comparisons (post-hoc tests) do not reveal any specific difference. This means that the actual differences between speeds were so small and not meaningful in practical terms. It's noteworthy that there was no Speed x Group interaction and no group main in terms of SmO₂, tHb, O₂Hb and HHb. While the absence of significant differences may seem unexpected, it does not negate the existence of baseline differences between athletes and sedentary individuals. Instead, it underscores the complexity of physiological responses. It highlights the need for further investigation into the underlying physiological mechanisms driving these responses in hamstring muscle fibers, e.g., Oxygen Extraction Kinetics, Metabolic Pathways etc. or with larger sample sizes, and different measurement techniques.

One of the possible explanations of having no difference between group, while the study group, i.e, volleyball athletes, engage in specific training that emphasizes lower body explosiveness and power, the BF muscle may not be heavily targeted or significantly affected by volleyball-specific training routines. As a result, differences in muscle oxygenation and Hb dynamics between sedentary individuals and volleyball athletes may not be manifested in this study.

Previous research has suggested that parameters such as SmO₂ or the Hb Diff (difference between HHb and O₂Hb) may offer a more precise evaluation of muscle oxygenation. We used SmO₂ in our study and it has shown differences with varying speeds. For VL, with high intensity, there is more reduction, and with low intensity, there is less reduction in SmO₂, which is in line with previous study results and has proved to be the best possible parameter to assess muscle oxygen extraction. Also, we found there was Hb Diff with varying speeds in both VL and BF, instead of no difference observed in HHb. By considering the limitations of HHb in the presence of tHb instability, future research can use these alternative parameters i.e, SmO₂ and Hb.Diff to enhance the accuracy of muscle oxygen extraction assessments using NIRS.

The study conducted by Perentis et al. (2023) aimed to investigate the impact of cycling and specifically targeted CON and ECC high-intensity interval exercises on oxygen levels in the skeletal muscle (specifically the VL) and the brain [188]. Twelve healthy men who undertook cycling exercises and isokinetic exercises focused on either CON or ECC muscle contractions, in a randomized sequence. These exercises effects on muscle and brain oxygenation were evaluated by measuring levels of O_2Hb , HHb , tHb and TSI . Each participant executed seven sets of seven-second bursts of maximum effort, with the resistance set at 7.5% of their body weight. Meanwhile, for the isokinetic exercises—both CON and ECC—the regimen consisted of seven sets of five maximum-effort muscle contractions. It was observed that the cycling protocol induced more fatigue than the isokinetic exercises. The findings indicated a reduction in ΔO_2Hb and a rise in ΔHHb , showing a decrease in muscle oxygenation suggesting that cycling protocol was intense enough to cause a decline in performance and noticeable changes in both muscle and brain oxygenation levels. The results were partly in parallel with our study for the decrease in SmO_2 . In contrast, the isokinetic exercises did not lead to significant changes in the fatigue index, possibly due to the exercises' lower volume.

In our study, we compared the effects of CON and ECC contractions at a speed of 60 isokinetic, finding that levels of tHb , O_2Hb , and $Hb\ Diff$ were higher in CON compared to ECC at the same speed, while no significant differences were observed in SmO_2 and HHb . Prior studies have suggested reduced muscle activation during ECC contractions compared to CON, despite similar or higher force output. Biopsies obtained from the VL muscle immediately after contractions showed a 55% lower phosphocreatine-to-creatine ratio in muscle fiber populations associated with ECC contractions compared to those with CON contractions.

Our findings, for VL, are consistent with a study conducted by Muthalib et al. (2009), which investigated the differences between ECC and CON contractions in terms of the oxygenation of the biceps brachii muscle (assessed using TOI) and its hemodynamics including tHb , O_2Hb , and HHb during 10 sets of 6 maximal contractions of the elbow flexors in a group of 10 healthy participants [189]. The results indicated a 100% lower tHb for ECC compared to CON. While muscle blood flow typically increases in response to tissue metabolic demands, TOI remained stable despite greater blood flow observed in CON. The lower tHb observed

in ECC was attributed to the activation of a smaller maximal muscle mass. Similar results were seen in our findings.

The similar SmO_2 levels between the two conditions indicate that the overall oxygen saturation within the muscle tissue remains unchanged. This suggests that while oxygen delivery may increase during CON 60, it is balanced by an increase in oxygen consumption. The heightened metabolic demands increase blood flow can lead to a greater delivery of oxygenated blood to the muscle tissue, resulting in elevated levels of tHb and O_2Hb . Another explanation is Increased metabolic activity during CON contractions may lead to more pronounced vasodilation and blood vessel recruitment to meet the heightened demand for oxygen delivery to the active muscle fibers. We can say that ECC exercise places less strain on the cardiovascular and metabolic systems, making it potentially a safer option (for older people or people with cardiovascular issue) exercise in certain areas of, rehabilitation, or training. However, it's essential to consider that ECC mode does subject muscles, myotendinous junctions, and tendons to increased mechanical stress.

The effects of negative work on physiology were examined by Abbott, Bigland, and Ritchie (2000) using two subjects on opposing bicycle ergometers [190]. Oxygen consumption during CON work was compared to that during ECC work, with leg muscles exerting equal forces in comparable movements at identical speeds. Their findings revealed that CON work consistently demanded higher oxygen consumption compared to ECC work. At a pedaling speed of 35 rev/min, the ratio of oxygen consumption between the two tasks stood at 3.7. This ratio rose as the pedaling speed increased. They suggested that the decrease in lactate concentration following the ECC set could stem from a "mechanical" disruption of actin-myosin crossbridge, independent of adenosine triphosphate, or from the extended distance traveled by each actin-myosin crossbridge.

Previous studies have demonstrated that CON exercise recruits a greater number of motor units compared to ECC exercise [191-193]. Physiologically, it is recognized that both heart rate and blood pressure responses elevate as the active muscle mass increases, although this relationship may not always be linear. In ECC contractions where muscle activation is lower, intramuscular forces decrease, leading to a reduction in mean arterial pressure [194, 195].

For BF, comparing CON and ECC, Hb Diff was higher in volleyball athletes compared to sedentary individuals during CON and ECC 60°/sec. This can be attributed to effective oxygen utilization in volleyball athletes. In terms of speed, Hb Diff and O₂Hb in the 60°/sec ECC was statistically higher than in the speed CON 60°/sec. These differences might be due to the anatomical and different muscle recruitment pattern in hamstrings.

Exercise training enhances skeletal muscle blood flow capacity through structural vascular remodeling, which involves the formation of new capillaries (angiogenesis) and the reorganization of the arterial network within skeletal muscle. Additionally, it may involve alterations in the regulation of vascular resistance [196, 197].

Exercise exerts immediate mechanical influences on arteries through repeated exposure to elevated blood pressure, increased blood flow, and enhanced arterial shear stress experienced during each session of physical activity. The endothelial shear stress serve as a powerful physiological trigger for the endothelium to produce paracrine hormones like prostaglandins and nitric oxide (NO) [198]. There is direct impact of exercise on the blood vessel wall, due to the recurring stimulation from the circulation during each session of exercise [196]. Enhanced vasodilation mediated by the endothelium or a decrease in the thickness of the inner layers of the artery could account for the improved flexibility of arteries [197].

In terms of group, for VL muscle, there was a difference in terms of tHb, O₂Hb, and HHb in between sedentary and volleyball athletes. The total blood flow measures of volleyball athletes were higher than those of sedentary individuals. We associate this improvement with enhanced endothelium-mediated vasodilation or a decrease in intima-media wall thickness, along with improved arterial compliance observed in volleyball athletes. Additionally, left ventricular diastolic function is considered a significant factor influencing cardiorespiratory fitness in physically active individuals, as volleyball athletes engage in regular physical activity [197,199,200]. Another explanation is their training-induced improvements in capillary density, mitochondrial density, and oxidative enzyme activity. These adaptations enhance oxygen extraction and utilization within muscle tissue. It's thought that the ability of the left ventricle to relax during its filling phase is a significant factor influencing cardiovascular fitness in athletes.

The limitations of our study include the fact that the sample consisted solely of male participants, potentially limiting the generalizability of our findings to the broader population and analyzing only on the dominant leg.





6. CONCLUSION AND RECOMMENDATIONS

The results and recommendations drawn from this study, which was designed to investigate potential differences in SmO₂ and tHb within the VL, as well as in, BF muscle, between sedentary individuals and athletes during isokinetic maximal CON and ECC contractions executed at varying speeds are listed below.

- In the VL, SmO₂, tHb and O₂Hb levels at a velocity of 300°/sec were substantially greater compared to lower speeds, while HHb values did not show any differences among the speeds. This implies that the VL muscle may benefit from higher velocity exercises without inducing fatigue symptoms, possibly enhancing performance and recovery.
- In the BF, only Hb Diff was found to be significantly greater during 300°/sec compared to 60°/sec.
- The discovery of no variations in HHb but distinctions in Hb Diff, since HHb is insensitive to changes in tHb, suggests focusing on Hb Diff rather than HHb to assess oxygen extraction accurately during different exercises in future research.
- The higher total blood flow measures in the VL of volleyball athletes compared to sedentary individuals, with no group differences found in blood flow measures in the BF, suggest that volleyball training may induce muscle-specific vascular adaptations, particularly in the VL.
- In VL, Hb Diff, tHb, O₂Hb was higher in CON at 60°/sec than in ECC at 60°/sec, with no significant differences in HHb. In BF, there was a Speed x Group interaction effect on Hb Diff at 60°/sec, indicating higher values during ECC than CON for volleyball athletes, suggesting the importance of tailoring training to muscle-specific responses.
- It could be inferred that, in rehabilitation settings, especially after knee or quadriceps injuries, incorporating CON-focused exercises can aid in enhancing blood flow and oxygen delivery, expediting healing. Moreover, incorporating ECC hamstring exercises can be beneficial to strengthen the hamstrings and enhance overall performance.

The acquired data can be practically utilized within the realm of determining the most effective training load parameters. NIRS device allows for gathering internal load data from athletes, which coaches and practitioners can use to assess and adjust training (and competition) parameters using various oxygenation metrics. It's time to start incorporating

muscle oxygenation metrics along with traditional methods like heart rate and Rate of Perceived Exertion to better measure internal training loads.



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APPENDICES

APPENDIX -1. Ethical Committee Document

Evrak Tarih ve Sayısı: 05.10.2023-E.764214	
 T.C. GAZİ ÜNİVERSİTESİ REKTÖRLÜĞÜ Etik Komisyonu	
Sayı : E-77082166-302.08.01-764214	05.10.2023
Konu : Bilimsel ve Eğitim Amaçlı	
Dağıtım Yerlerine	
Üniversitemiz Sağlık Bilimleri Enstitüsü Fizyoterapi ve Rehabilitasyon Ana Bilim Dalı Yüksek Lisans Öğrencisi Dur SAMAND'ın, Prof. Dr. Nevin Aysel GÜZEL'in danışmanlığında yürüttüğü "Sporcularda Farklı Hızlarda İzokinetik Konsantrik ve Eksentrik Kasılma Anında Kas Oksijenasyonu ve Toplam Hemogloblin Düzeylerinin Karşılaştırılması" adlı tez çalışması ile ilgili konu Komisyonumuzun 03.10.2023 tarih ve 17 sayılı toplantısında görüşülmüş olup, İlgilinin çalışmasının, yapılması planlanan yerlerden izin alınması koşuluyla yapılmasında etik açıdan bir sakınca bulunmadığına oybirliği ile karar verilmiş ve karara ilişkin imza listesi ekte gönderilmiştir. Bilgilerinizi rica ederim. Araştırma Kod No: 2023 - 1142	
Prof. Dr. İsmail KARAKAYA Komisyon Başkanı	
Ek:1 Liste	
DAĞITIM	
Gereği:	Bilgi:
Sayın Prof. Dr. Nevin Aysel GÜZEL	Sağlık Bilimleri Enstitüsü Müdürlüğüne
Bu belge, güvenli elektronik imza ile imzalanmıştır. Belge Doğrulama Kodu :BSDF988UN2 Belge Takiye Adresi : https://www.turkiye.gov.tr/gazi-universitesi-ebvs	
Enstitü Mahallesi Bandırma Caddesi No :6/1 06560 Yenimahalle/ANKARA Tel:0 (312) 202 28 57 - 0 (312) 2... Faks:0 (312) 202 38 76 İnternet Adresi :http://etikkomisyonu.gazi.edu.tr/ Kayıt Adresi: gaziuniversitesi@h601.kep.tr	Bilgi için :Ayfer Çekmez Genel Evrak Sorumlusu Telefon No:202 38 81
Bu belge,güvenli elektronik imza ile imzalanmıştır.	

APPENDIX -1. (Continued) Ethical Committee Document

Evrak Tarih ve Sayısı: 05.10.2023-E.764214		GAZİ ÜNİVERSİTESİ	
ETİK KOMİSYONU KATILIM LİSTESİ			
TOPLANTI TARİHİ : 03.10.2023		TOPLANTI SAYISI : 17	
ADI – SOYADI	İMZA		
Prof. Dr. İsmail KARAKAYA BAŞKAN			
Prof. Dr. Zehra GÖÇMEN BAYKARA BAŞKAN YRD.			
Prof. Dr. C. Haluk BODUR			
Prof. Dr. Seçil ÖZKAN			
Prof. Dr. Cevriye TEMEL GENCER			
Prof. Dr. İlkay ULUTAŞ			
Prof. Dr. Kemalettin DENİZ			
Prof. Dr. Makbule GEZMEN KARADAĞ			
Prof. Dr. İlyas OKUR			
Prof. Dr. Nihan KAFA			
Doç. Dr. Melek Gülşah ŞAHİN			
Doç. Dr. Gökhan DELİCEOĞLU			
Doç. Dr. Elvan İNCE AKA			

APPENDIX -2. Participants Consent Form

GAZİ ÜNİVERSİTESİ ETİK KOMİSYONU FORM-2
Rev-2
25.01.2022

T.C.
GAZİ ÜNİVERSİTESİ
ETİK KOMİSYONU



KATILIMCILAR İÇİN BİLGİLENDİRİLMİŞ GÖNÜLLÜ OLUR FORMU

Sizi, Gazi Üniversitesi Etik Komisyonu'ndan tarih / sayı ile izin alınan* ve Prof. Dr. Nevin Aysel Güzel tarafından yürütülen "Sporcularda Farklı Hızlarda İzokinetik Konsentrik ve Eksantrik Kasılma Anında Kas Oksijenasyonu ve Toplam Hemogloblin Düzeylerinin Karşılaştırılması" başlıklı araştırmaya davet ediyoruz. Bu çalışmaya katılmak tamamen gönüllülük esasına dayanmaktadır. Çalışmaya katılmama veya katıldıktan sonra herhangi bir anda çalışmadan çıkma hakkına sahipsiniz. Bu çalışmaya katılmanız için sizden herhangi bir ücret istenmeyecektir. Çalışmaya katıldığınız için size bir ödeme yapılmayacaktır. Çalışmadan elde edilecek bilgiler tamamen araştırma amacı ile kullanılacak olup kişisel bilgileriniz gizli tutulacaktır.

*Gazi Üniversitesi Etik Komisyon izni alındıktan sonra doldurularak kullanılacaktır.

Araştırmanın Amacı	Farklı türde egzersizler yaptığınızda bacak ve uyluk kaslarınızın nasıl çalıştığını incelemek istiyoruz. Siz belirli hareketleri yaparken bu kaslardaki oksijen seviyelerine ve kan akışına bakacağız. Ayrıca bu bilgileri çok egzersiz yapan ve yapmayan kişiler arasında karşılaştırmak istiyoruz.
Araştırmanın Yöntemi	Araştırmanın başında deri kıvrımı kalınlığınız kaliper ile ölçülecek. Ardından TANITA vücut kompozisyonu cihazı ile vücut ağırlığı ve segmental yağ yüzdeniz belirlenecek. Son olarak izokinetik sistemde bacak kaslarınızın farklı kasılma anlarında kuvveti ve bu esnada kanlanmasına NIRS Train.Red FYER marka aletle bakılacak. Bu ölçümlerin hiçbirisi ağrı oluşturan ya da deri bütünlüğünü etkileyen ölçümler değildir. Tüm değerlendirmeler ortalama 30 dakika sürecektir.
Araştırmanın Öngörülen Süresi (Başlama ve Bitiş Tarihi Başvurudaki Başlangıç ve Bitiş Tarihi ile Uyumlu Olmalıdır.)	1.11.2023 - 1.1.2024
Araştırmaya Katılması Beklenen Katılımcı/Gönüllü Sayısı	34
Araştırmanın Yapılacağı Yerler	Gazi Üniversitesi, Sağlık Bilimleri Fakültesi, Fizyoterapi ve Rehabilitasyon Bölümü, Sporcu Sağlığı Ünitesi
Görüntü ve/veya ses kaydı alınacak mı?	Evet ☐ Hayır ☒

Tablo katılımcıların anlayabileceği biçimde, akademik dil kullanılmadan yazılacaktır.

KATILIMCI BEYANI

Yukarıda amacı ve içeriği belirtilen bu araştırma ile ilgili bilgiler tarafıma aktarıldı. Bu bilgilerden sonra araştırmaya katılımcı olarak davet edildim. Bu çalışmaya katılmayı kabul ettiğim takdirde gerek araştırma yürütülürken gerekse yayımlandığında kimliğimin gizli tutulacağı konusunda güvence aldım. Bana ait verilerin kullanımına izin veriyorum. Araştırma sonuçlarının eğitim ve bilimsel amaçlarla kullanımı sırasında kişisel bilgilerimin dikkatle korunacağı konusunda bana yeterli güven verildi. Araştırmanın yürütülmesi sırasında herhangi bir sebep göstermeden çekilebilirim. Araştırma için yapılacak harcamalarla ilgili herhangi bir parasal sorumluluk altına girmiyorum. Bana herhangi bir ödeme yapılmayacaktır. Araştırma ile ilgili bana yapılan tüm açıklamaları ayrıntılarıyla anlamış bulunmaktayım. Bu çalışmaya hiçbir baskı altında kalmadan kendi bireysel onayım ile katılıyorum. İmzalı bu form kağıdının bir kopyası bana verilecektir.

Araştırma yürütücüsü(Tez çalışmalarında Danışman tarafından imzalanacaktır.)

Adı ve Soyadı	Prof. Dr. Nevin Aysel Güzel	Tarih ve İmza
Adres ve telefonu	Gazi Univ. Sağlık Bilimleri Fak.	26.09.2023

Katılımcı

APPENDIX-2. (Continued) Participant Consent Form

GAZİ ÜNİVERSİTESİ ETİK KOMİSYONU FORM-2		
Rev-2 25.01.2022		
Adı ve Soyadı		Tarih ve İmza
Adres ve telefonu		
Velayet veya Vesayet Altındaki Katılımcılar için Veli/Vasi		
Adı ve Soyadı		Tarih ve İmza
Adres ve telefonu		

APPENDIX -3. Assessment Form (For Volleyball Athletes)

DEĞERLENDİRME FORMU

Adı-Soyadı:

Özgeçmiş:

Yaş:

- Bacak yaralanması varlığı:

Ağırlık :

- Respiratuar hastalık veya herhangi bir kardiyovasküler hastalık varlığı:

Boy:

Meslek:

Soy geçmiş:

Eğitim düzeyi:

Dominant taraf:

Spora başlama yaşı:

Tel:

Haftalık antrenman saati:

Adres:

Lisanslı bir sporcu musunuz?

Spor mevkisini?

Sigara kullanıyor musunuz :

İlaçlar:

Tanita Ölçümü:

Skinfold Kaliper Ölçümü:

İzokinetik sistem	1. Ölçüm		2. Ölçüm	
	Sağ	Sol	Sağ	Sol
60°/sn konsentrik				
180°/sn konsentrik				
300°/sn konsentrik				
60°/sn eksentrik				

APPENDIX -4. Assessment Form (For Sedentary Individuals)

DEĞERLENDİRME FORMU

Adı-Soyadı:

Özgeçmiş:

Yaş:

- Bacak yaralanması varlığı:

Ağırlık :

- Respiratuar hastalık veya herhangi bir kardiyovasküler hastalık varlığı:

Boy:

Meslek:

Eğitim düzeyi:

Soy geçmişi:

Dominant taraf:

Sigara kullanıyor musunuz :

Tel:

İlaçlar:

Adres:

Tanita Ölçümü:

Skinfold Kaliper Ölçümü:

İzokinetik sistem	1. Ölçüm		2. Ölçüm	
	Sağ	Sol	Sağ	Sol
60°/sn konsentrik				
180°/sn konsentrik				
300°/sn konsentrik				
60°/sn eksentrik				

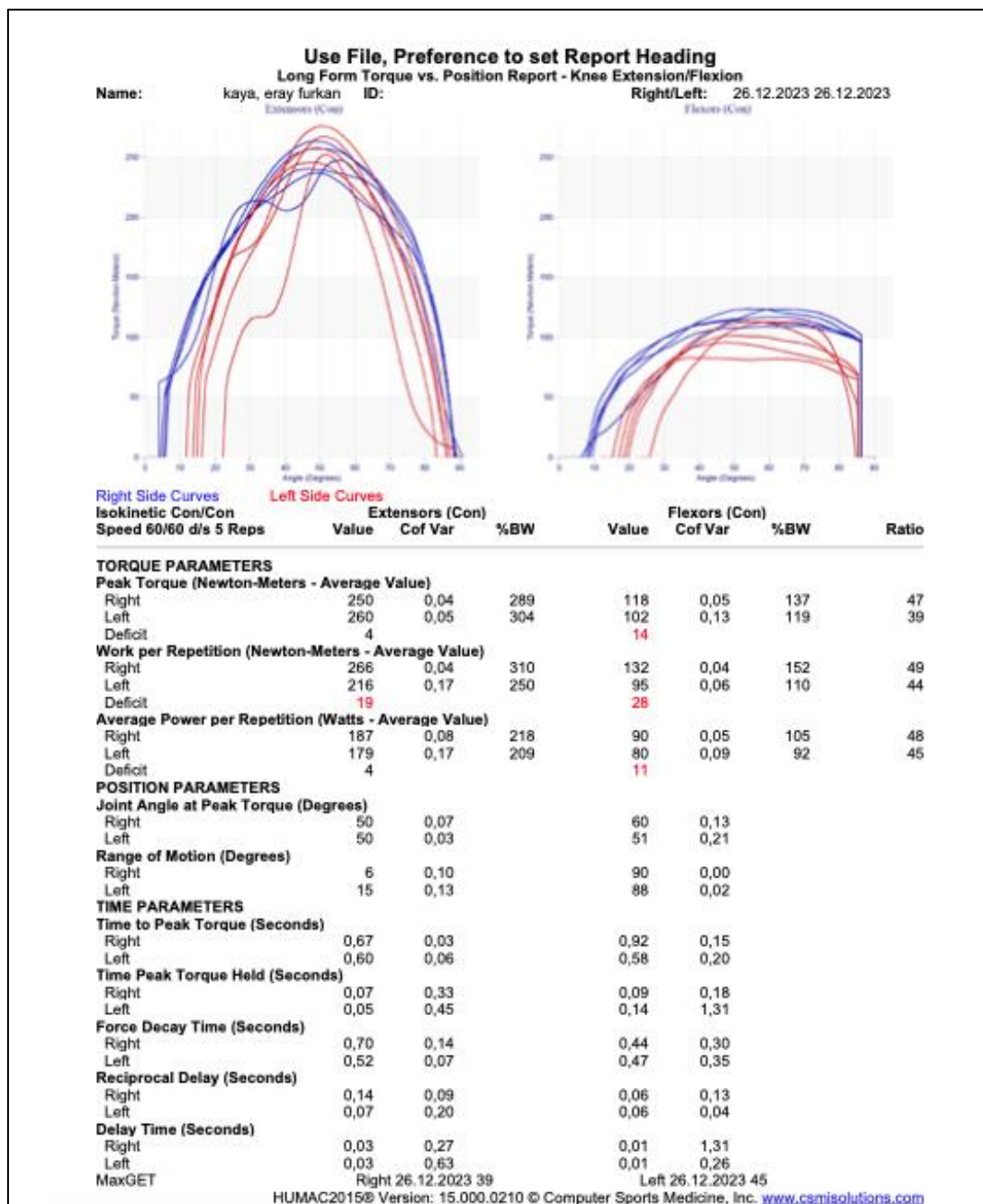
APPENDIX -5. Sample Body Composition Analysis Report

TANITA BODY COMPOSITION ANALYZER BC-418			
28 JAN 2022		12:01	
BODY TYPE	STANDARD		
GENDER	FEMALE		
AGE	30		
HEIGHT	160	cm	
WEIGHT	58.8	kg	
BMI	23.0		
BMR	5134	kJ	
	1227	kcal	
FAT%	33.1	%	
FAT MASS	19.5	kg	
FFM	39.3	kg	
TBW	28.8	kg	
VISCERAL FAT RATING	3		
DESIRABLE RANGE			
FAT%	21-33%		
FAT MASS	10.5-19.4 kg		
IMPEDANCE			
Whole Body	784	Ω	
Right Leg	332	Ω	
Left Leg	336	Ω	
Right Arm	405	Ω	
Left Arm	422	Ω	
Segmental Analysis			
Right Leg			
Fat%	38.3	%	
Fat Mass	4.1	kg	
FFM	6.6	kg	
Predicted Muscle Mass	6.2	kg	
Left Leg			
Fat%	38.4	%	
Fat Mass	4.1	kg	
FFM	6.5	kg	
Predicted Muscle Mass	6.1	kg	
Right Arm			
Fat%	31.4	%	
Fat Mass	0.9	kg	
FFM	1.9	kg	
Predicted Muscle Mass	1.8	kg	
Left Arm			
Fat%	32.9	%	
Fat Mass	0.9	kg	
FFM	1.9	kg	
Predicted Muscle Mass	1.8	kg	
Trunk			
Fat%	29.9	%	
Fat Mass	9.5	kg	
FFM	22.4	kg	
Predicted Muscle Mass	21.4	kg	

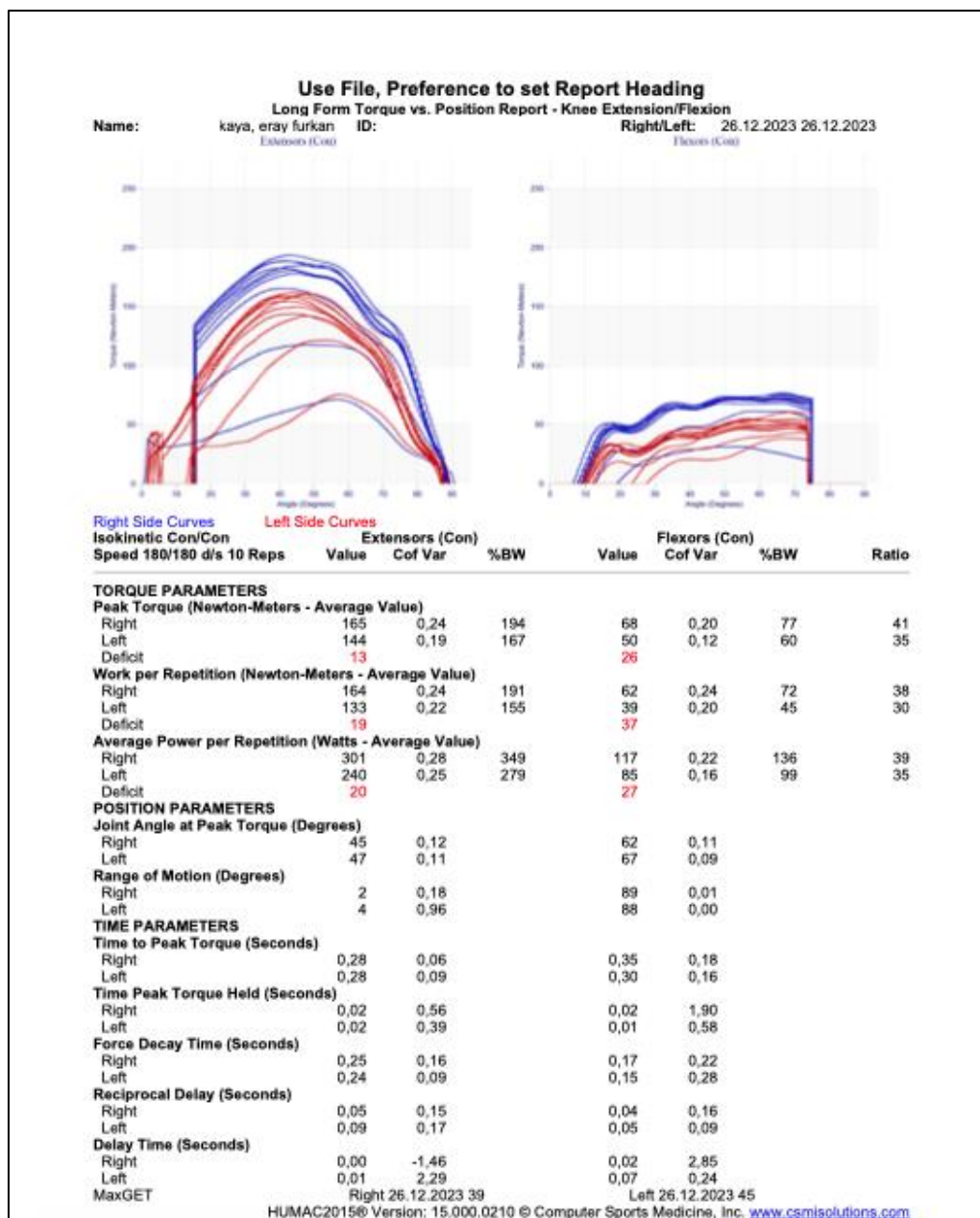
APPENDIX -6. TRAIN.RED Data Sample

A1 ⌵ ⋮ ✕ ✓ <i>fx</i> Activity									
	A	B	C	D	E	F	G	H	I
1	Activity	STRENGTH_TRAINING							
2	Session Ty	STRENGTH							
3	Duration[h	0:00:15							
4									
5									
6	Sensor nar	Sensor ma	Sensor pos	SmO2 star	HBDiff star	SmO2 var	MSS	Firmware version	
7	Train.Red	F0:48:C9:(	Not Positio	71	24	10	1	2.0.21	
8	Timestamp	SmO2 filte	HBDiff filte	O2HB unfil	HHb unfilte	Muscle state			
9	0.026	71.3	24.9	83.7	59	1			
10	0.055	71.3	24.8	83.7	59	1			
11	0.055	71.4	24.8	83.7	59.1	1			
12	0.144	71.4	24.8	83.8	59.1	1			
13	0.235	71.5	24.7	83.8	59.1	1			
14	0.478	71.5	24.7	83.7	59.1	1			
15	0.482	71.6	24.7	83.8	59.1	1			
16	0.535	71.6	24.7	83.8	59.1	1			
17	0.656	71.7	24.7	83.7	59.1	1			
18	0.866	71.7	24.7	84.3	59.4	1			
19	0.868	71.6	24.7	84.9	59.8	2			
20	1.075	71.3	24.8	84.6	60.1	2			
21	1.076	70.9	24.7	84.2	60.3	2			
22	1.135	70.4	24.6	83.7	60.6	2			
23	1.348	69.7	24.3	83.7	60.2	2			
24	1.35	69.4	24	83.8	59.8	2			
25	1.466	69.5	23.9	83.2	59.3	5			
26	1.555	69.6	23.8	83.8	59.5	5			
27	1.645	69.2	23.8	83.5	59.4	5			
28	1.735	68.5	23.9	83	59.1	5			
29	1.975	67.7	23.9	83.3	59	5			
30	1.978	66.8	24	83.2	58.9	5			

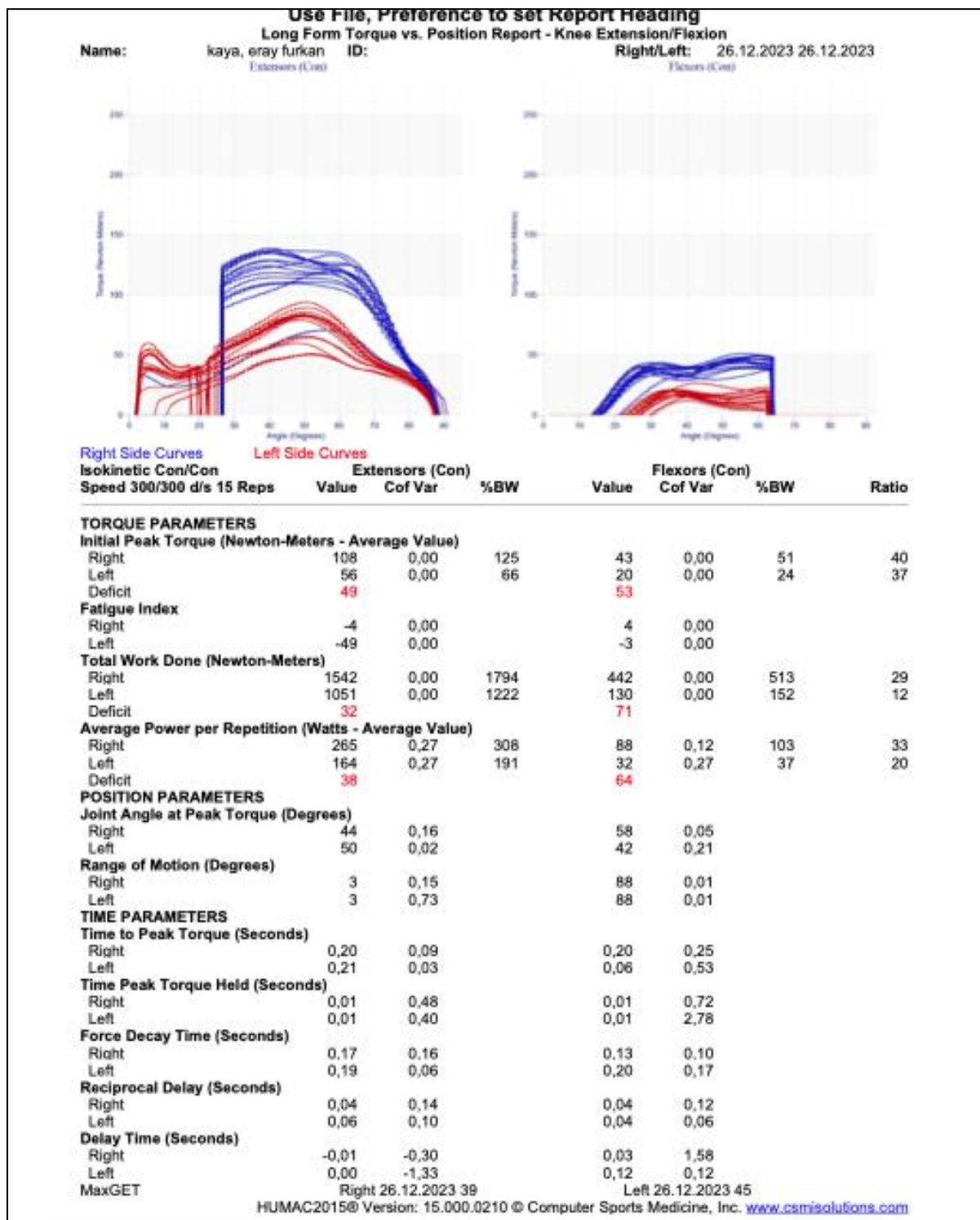
APPENDIX -7. Isokinetic Knee Muscle Strength Report Example



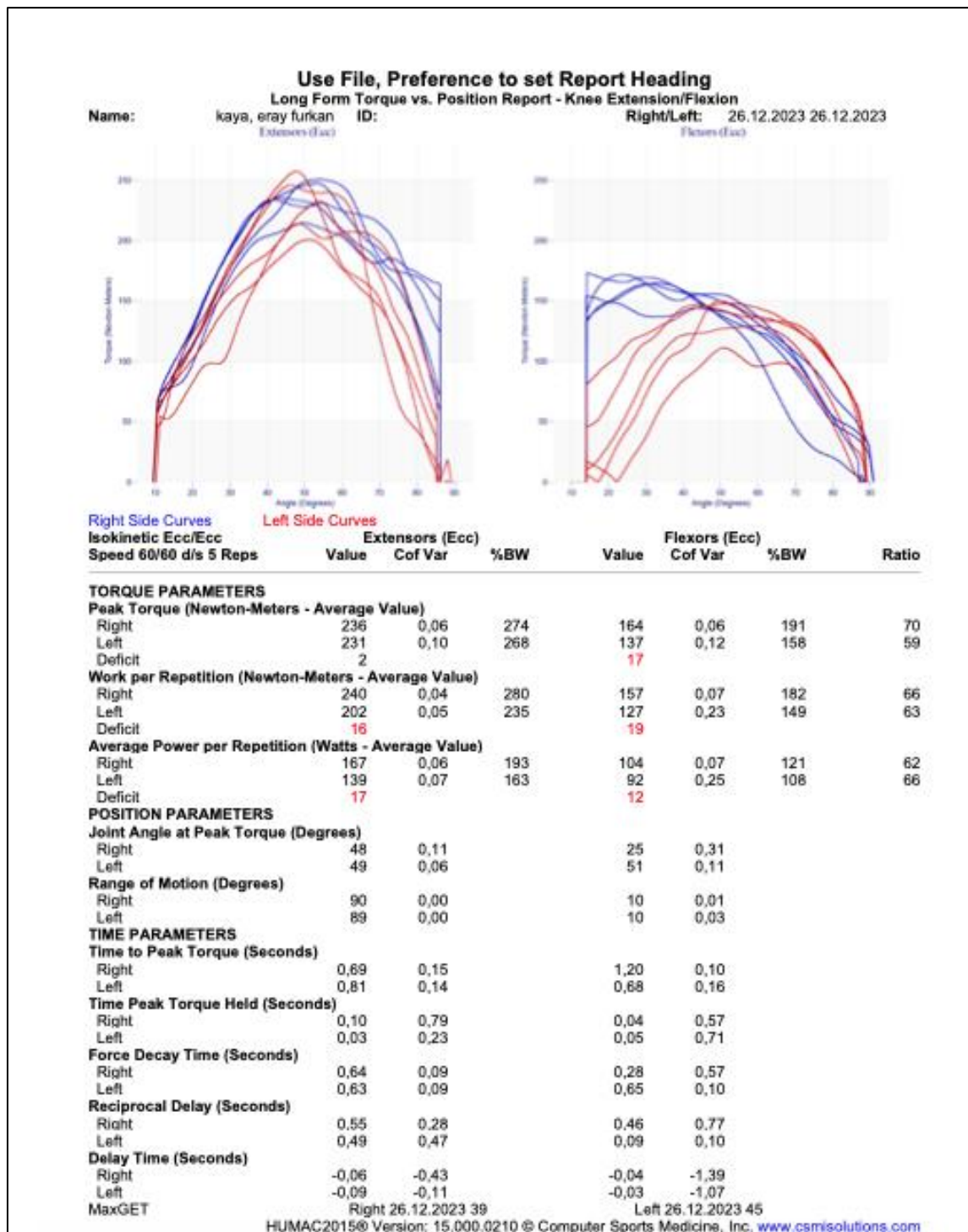
APPENDIX -7. (Continued) Isokinetic Knee Muscle Strength Report Example



APPENDIX -7. (Continued) Isokinetic Knee Muscle Strength Report Example



APPENDIX -7. (Continued) Isokinetic Knee Muscle Strength Report Example



CURRICULUM VITAE

Personal Information:

Surname, name : SAMAND, Dur

Nationality : Pakistani

Education

Degree	Department	Graduation Date
Master's degree	Gazi University / Department of Physiotherapy and Rehabilitation	Ongoing
Undergraduate	Khyber Medical university/Institute of Physical Medicine & Rehabilitation Sciences	2020
Higher Secondary	Gazi University/ Department of Industrial Engineering	2014

Work Experience

Year	Place	Duty
2020-2021	PEF University, Pakistan	Lecturer/Clinical Incharg
2020	University of Peshawar	Teaching Assistant

Foreign Language

English, Turkish

Hobbies

Reading and Music



GAZİLİ OLMAK AYRICALIKTIR...