VNIVERSITAT DE VALÈNCIA Facultat de Fisioteràpia

PROGRAMA DE DOCTORADO EN FISIOTERAPIA

VALIDEZ Y FIABILIDAD DE UN DINAMÓMETRO DE TENSIÓN COMO HERRAMIENTA DE EVALUACIÓN DE LA FUERZA ISOMÉTRICA Y ELÁSTICA

TESIS DOCTORAL

Presentada por:

Javier González Rosalén

Dirigida por:

Dr. Rodrigo Martín de San Agustín

Dr. Josep C. Benítez Martínez

Valencia, Noviembre de 2022.

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CERTIFICAN que el trabajado presentado como Tesis Doctoral por D. Rodrigo Martín San Agustín, titulado **VALIDEZ Y FIABILIDAD DE UN DINAMÓMETRO DE TENSIÓN COMO HERRAMIENTA DE EVALUACIÓN DE LA FUERZA ISOMÉTRICA Y ELÁSTICA,** ha sido realizado bajo nuestra dirección y consideramos que reúne las condiciones apropiadas en cuanto a contenidos y rigor científico para ser presentado a trámite de lectura.

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Índice

Índice de abreviaturas

OMS: Organización Mundial de la Salud

TME: Trastornos Musculoesqueléticos

AESST: Agencia Europea para la Seguridad y la Salud en el Trabajo

RM: Repetición Máxima

DMP: Dinamometría Manual Portátil

TUT: Tiempo Bajo Tensión

ROM: Rango Completo de Movimiento

EVA: Escala Visual Analógica

FIM: Fuerza Isométrica Máxima

CIVM: Contracciones Isométricas Voluntarias Máximas

DE: Desviación Estándar

IC: Intervalo de Confianza

LOA: Límites del Acuerdo

ICC: Coeficiente de Correlación Intraclase

SEM: Error Estándar de Medición

MDC: Mínimo Cambio Detectable

Índice

1. Introducción 3

1.1 Objetivos 10

2. Material y métodos 11

2.1. Diseño y sujetos. 11

2.2. Procedimientos. 12

2.2.1. Metodología de la evaluación 12

2.2.2. Recolección de datos 16

2.3. Análisis estadístico. 24

3. Resultados 27

4. Conclusiones 29

5. Referencias bibliográficas 31

Anexos 43

Resumen de la tesis

1. Introducción

La inactividad física se ha identificado como uno de los cuatro principales contribuyentes a la mortalidad prematura junto a la hipertensión arterial, el tabaquismo y las enfermedades cardiovasculares y/o cardiometabólicas (diabetes, obesidad, etc) (McCambridge et al., 2019; Panahi & Tremblay, 2018). A pesar de conocer los beneficios que tiene el ejercicio físico para la salud, los niveles de actividad física en la población global no han aumentado desde 2001, de acuerdo a la Organización Mundial de la Salud (OMS). Además, en los países con altos ingresos per cápita, la población con insuficientes niveles de actividad física ha aumentado un 5% desde el 2001 al 2016 (31.6% a 36.8%) debido a la instauración de hábitos de vida y trabajo más sedentarios (con un consumo energético menor a 1.5 equivalentes metabólicos), o la utilización de medios de transporte menos activos (Lin & Cui, 2021; Pucher & Dijkstra, 2003).

Una de las consecuencias de esta falta de actividad física es la sarcopenia precoz (Gómez, 2011). La sarcopenia, o pérdida de masa muscular asociada al envejecimiento, hace referencia a la pérdida involuntaria de masa muscular esquelética que se produce con la edad. Se ha comprobado que la masa muscular comienza a declinar a partir de la tercera década, produciéndose de manera habitual un declive más marcado al final de la quinta década (Dhillon & Hasni, 2017). Se trata de una alteración muy frecuente en la población mayor de 65 años, observándose incluso en adultos mayores que realizan una actividad deportiva intensa (Giallauria et al., 2016; Gómez, 2011). Durante su curso se describen varios elementos que la caracterizan, entre los cuales se encuentra: la disfunción mitocondrial o el estrés oxidativo, asociado frecuentemente a la pérdida o disminución de la síntesis de proteínas de contracción, lo que a largo plazo genera atrofia, menor formación de trifosfato de adenosina, y finalmente desaparición de la fibra muscular (Dhillon & Hasni, 2017; Giallauria et al., 2016; Hernández-Rodríguez et al., 2017). A pesar de que el nivel de fuerza necesario para satisfacer las exigencias de la vida cotidiana no varía mucho a lo largo de la vida; con el incremento del envejecimiento celular se produce una disminución en la producción de fuerza máxima, lo cual dificulta la realización de funciones previamente llevadas a cabo sin problema.

Los cambios a nivel muscular inducidos por la sarcopenia no pueden ser únicamente atribuidos a la disminución progresiva de la actividad física con el envejecimiento, a pesar de ello, un estilo de vida con una baja actividad física priva a la musculatura de un estímulo prioritario para mantener tanto su masa como su función (Gómez, 2011; González-Gross & Meléndez, 2013). Cuando hablamos de sarcopenia, se admite que los ejercicios de fuerza y resistencia resultan beneficiosos, tanto en varones como en mujeres, considerándose la realización de actividad física la medida terapéutica más eficaz para prevenir y tratar la sarcopenia (Dhillon & Hasni, 2017; Giallauria et al., 2016; González-Gross & Meléndez, 2013; Law et al., 2016; Lin & Cui, 2021; Pucher & Dijkstra, 2003; Rubio del Peral et al., 2018). La relación existente entre sarcopenia, pérdida de fuerza y pérdida de función es evidente. La relación entre estos factores y la patología no es directa, si bien es cierto, la inactividad física y la pérdida de fuerza supone un factor de riesgo para el desarrollo de trastornos musculoesqueléticos (TME)(Dhillon & Hasni, 2017; Gómez, 2011; Lin & Cui, 2021). Es sabido que, los TME, que afectan principalmente a cuello, hombros y extremidades tanto superiores como inferiores, representan las dolencias más habituales en el ámbito laboral, afectando aproximadamente a 1.710 millones de personas en toda el mundo, según cifras de la Agencia Europea para la Seguridad y la Salud en el Trabajo (AESST). Entre los factores de riesgo para la aparición de TME encontramos tanto internos como externos. Los factores de riesgo externos son aquellos condicionados por el contexto (Ej: altas exigencias en el trabajo, posturas, movimientos repetitivos, etc) y los internos son aquellos condicionados por el propio sujeto (Ej: genética, tabaquismo, nivel cultural, etc)(Rizo & Ubago, 2018; Shappardz, 2000). Dentro de los factores de riesgo internos, cabe destacar aquellos sobre los que podemos actuar de manera individual, entre los que encontramos la capacidad física y el estilo de vida o los hábitos de salud (como la falta de actividad física). En relación con esto último, se aprecia en sujetos con patología o síntomas, tanto en el miembro superior como inferior, una evidente pérdida de fuerza que se mantiene en el tiempo, produciendo cambios en la actividad motora y asociándose habitualmente con el dolor y el disconfort (FAPTA, 2001; Struyf et al., 2015).

A pesar de que no exista evidencia firme que relacione la práctica de ejercicio físico y la disminución del dolor, en los últimos años existe un interés creciente en la aplicación de ejercicio físico a fin de mejorar la capacidad de sujetos con síntomas, o prevenir la aparición de dichos síntomas en sujetos sin patología (Andersen et al., 2011; Magnus et al., 2014; Philadelphia Panel, 2001). El proceso mediante el cual se aplica ejercicio con el objetivo de corregir, recuperar y/o mejorar alguna estructura o función es conocido como la prescripción de ejercicio terapéutico (Brody, 2012). Además de la adecuación de la pauta, el ejercicio como herramienta terapéutica conlleva la realización repetida de manera regular de dicha pauta, así como la evaluación de los efectos de la misma, con el objetivo de reevaluar constantemente la adecuación de la misma. Si la prescripción y el cumplimiento de la pauta son adecuados, la aplicación de ejercicio regular es potencialmente beneficioso tanto para el tratamiento de los factores de riesgo asociados a los TME como para la mejora del curso de otras patologías comúnmente encontradas en la población general como son: la diabetes (Yanai et al., 2018; Yardley et al., 2014), la osteoporosis (Pinheiro et al., 2020), las enfermedades cardiovasculares (Pinckard et al., 2019), la artrosis (Miguéns Vázquez, 2021), y/o afecciones que engloban otros profesionales de la salud como la depresión (Sharma et al., 2006). Entre los efectos de un programa de fuerza están el incremento en la tolerancia y la resistencia a la fatiga, provocando una mejora en la capacidad funcional, aumento de la capacidad de resistencia de músculos crónicamente dolorosos (Sundstrup et al., 2016), y la disminución de la inflamación sistémica, observándose en laboratorio que los músculos que se contraen muestran tendencia a segregar citoquinas con propiedades antiinflamatorias (Moldoveanu et al., 2001; Windsor et al., 2018). A pesar de los potenciales beneficios, actualmente, existe evidencia que señala la necesidad de mejorar las características de la prescripción del ejercicio físico (Philadelphia Panel, 2001). Para poder realizar una prescripción adecuada, es necesario el manejo de dos elementos fundamentales: las expresiones de la fuerza y sus distintas variables.

En primer lugar, existen distintas expresiones de la fuerza. La fuerza máxima representa la mayor cantidad de fuerza que el organismo es capaz de realizar ante una resistencia predeterminada (McArdle et al., 2010). Cuando no es posible desarrollar el

mayor grado de fuerza, encontramos la fuerza submáxima, siendo necesario diferenciar a su vez entre la fuerza submáxima estática o isométrica, y la fuerza submáxima dinámica, dentro de la cual encontramos diferentes subclasificaciones, tales como la fuerza concéntrica, la fuerza excéntrica, la fuerza isocinética, la fuerza explosiva o la fuerza resistencia (Badillo & Ayestarán, 2002).

Del mismo modo, se han propuesto diversos métodos para cuantificar la fuerza muscular en sus diferentes expresiones. La evaluación de la fuerza muscular proporciona información clínica relevante. Entre otras funciones, permite cuantificar de manera objetiva la efectividad de un plan de tratamiento y observar desviaciones de la normalidad (Stark et al., 2011).

En el ámbito clínico, la fuerza muscular submáxima es la expresión de la fuerza de elección para la evaluación de un sujeto, incluyendo dentro de las variables de análisis la cuantificación de la fuerza voluntaria isométrica y el cálculo de la fuerza dinámica y sus subdivisiones (McArdle et al., 2010). Alguna de estas alternativas son las pruebas musculares manuales, la dinamometría isométrica de mano, el cálculo mediante la repetición máxima (RM) y la dinamometría isocinética (Brzycki, 1993; Stark et al., 2011).

La fuerza muscular dinámica es aquella que se produce como resultado de una contracción isotónica, que genera un cambio en el estado de reposo de los elementos contráctiles de la unidad muscular, disminuyendo o aumentando la longitud de la estructura (McArdle et al., 2010). Es posible diferenciar, dependiendo de la naturaleza del cambio en la estructura muscular, dos tipos de fuerza. Cuando se produce un acortamiento de la estructura muscular se genera un ciclo de contracción concéntrica. Cuando este cambio en la longitud de la estructura resulta en favor de la resistencia, se produce un aumento de la longitud de la estructura muscular, produciéndose un ciclo de contracción excéntrica (McArdle et al., 2010). La mayoría de las contracciones musculares combinan las contracciones de naturaleza isotónica con las contracciones de naturaleza isométrica. Esta conjugación de contracciones recibe el nombre de contracción auxotónica (McArdle et al., 2010). Dentro de la fuerza dinámica, existe una tercera posibilidad en la que se observa un ciclo de contracción muscular en el que se

mantiene una velocidad constante de contracción. Se genera un ciclo de contracción isocinético, que resulta de la combinación de contracciones musculares concéntricas y excéntricas, sin llegar a producirse periodos de contracción de naturaleza isométrica (Badillo & Ayestarán, 2002; McArdle et al., 2010).

La determinación de la fuerza máxima y submáxima dinámica se realiza a través de máquinas de musculación o pesos libres. Para el cálculo de ambas fuerzas, conocemos dos métodos, el método directo y el método indirecto. Con el método directo se establece la movilización de una determinada carga en una única RM. El método indirecto es una forma de estimar la RM sin ser necesario alcanzar el nivel de esfuerzo que conllevaría realizar el test directo. Existen diversas fórmulas como la de Brzycki (Brzycki, 1993) o la de Lander (Wood et al., 2002) a través de las cuales podemos calcular una aproximación a la RM a través de la realización de un test de menor exigencia. Más recientemente, el cálculo de la fuerza isocinética a través de la utilización del dinamómetro isocinético ha aumentado en el ámbito clínico (Baltzopoulos & Brodie, 1989; Stark et al., 2011). El desarrollo de sistemas informatizados para la dinamometría isocinética, ha generado un aumento de la eficacia y exactitud de las mediciones en la cuantificación de la fuerza. De cualquier modo, este tipo de aparatos no son portátiles y requieren procesos de preparación y calibración, lo cual hace que su utilización en clínica requiera tiempo y sea impráctica (Schrama et al., 2014; Stark et al., 2011).

Frente a las mediciones dinámicas, existe la determinación de la fuerza submáxima isométrica, realizándose a través de una contracción que no genera cambios en la longitud de la estructura muscular. Se observa un aumento de la tensión entre los puntos de origen e inserción muscular, pero sin llegar a producirse movimiento (Badillo & Ayestarán, 2002; McArdle et al., 2010). El método más utilizado en el cálculo de la fuerza isométrica es el test de evaluación manual de la fuerza muscular, descrito por Daniels y Worthingham (Schwartz et al., 1992). A pesar de ser un método económico, está sujeto a problemas relacionados con la subjetividad de las mediciones, la fiabilidad entre los rangos de normal a bueno y la fiabilidad entre examinadores. Además, es necesario que los terapeutas tengan una amplia experiencia previa para conseguir realizar mediciones precisas (Schwartz et al., 1992). Por ello, se han propuesto métodos

objetivos mediante dinamómetros manuales portátiles (DMP) para valorar la fuerza muscular isométrica (Schrama et al., 2014; Thorborg et al., 2013).

La DMP parece ser el método más apropiado para la objetivación de la fuerza isométrica. Ha sido desarrollada para valorar de manera objetiva la fuerza muscular isométrica, y de ese modo, poder analizar entre otros, la existencia de déficits musculares en la comparación de hemicuerpos o grupos musculares antagonistas, o la evolución, tanto dentro de un programa de rehabilitación en el ámbito clínico como en la prescripción de un programa de fortalecimiento en un contexto deportivo. Es portátil, se puede utilizar en el ámbito clínico, es relativamente sencilla de utilizar y ha demostrado tener una excelente fiabilidad intra e inter-examinador en la extremidad superior e inferior (Leggin et al., 1996; Suzuki, 2015; Thorborg et al., 2013). Además, se ha demostrado una menor influencia en cuanto a factores intrínsecos del examinador (edad, sexo) en comparación con otros métodos como la evaluación manual de la fuerza (Schwartz et al., 1992). La metodología en la que se basa la DMP ha evolucionado en los últimos años para garantizar que las mediciones tengan el mayor porcentaje de validez y fiabilidad en los contextos mencionados previamente. A pesar de que el mayor porcentaje de evidencia al respecto ha sido realizada mediante la utilización de dispositivos de DMP de presión, la limitación que supone la ausencia de estabilización y la influencia de la fuerza del examinador (Ej. hombre/mujer) en los valores obtenidos ha motivado un cambio en el planteamiento de la metodología de valoración (Kolber & Cleland, 2005; Schrama et al., 2014). Actualmente existen dos posibilidades que disminuyen la influencia tanto de la falta de estabilización del dispositivo como del sexo del examinador: la estabilización del dinamómetro de presión a través de un cinturón rígido, y la utilización de un dinamómetro de tracción (Katoh, 2015; Kolber et al., 2007; Romero-Franco et al., 2019). En el dinamómetro de presión fijado mediante cinturón rígido, el sujeto ejerce una presión sobre el dispositivo, generando una fuerza de tracción entre el dinamómetro y la estabilización. Puesto que la tracción es definida por la Real Academia Española como: “la acción de tirar de algo con el fin de moverlo o arrastrarlo”, el uso de la DMP de tracción sea quizá más adecuado en la evaluación de la fuerza isométrica.

Por otra parte, el análisis de las variables de la fuerza ha sido ampliamente estudiado en las últimas décadas con el fin de mejorar la prescripción e individualización del trabajo físico. La cuantificación y control de la intensidad, el volumen, la densidad, la frecuencia y la duración de un esfuerzo es fundamental para orientar adecuadamente los objetivos, tanto dentro de un programa de entrenamiento muscular en sujetos sanos como en un programa de rehabilitación en sujetos con patología. El manejo de las variables de entrenamiento antes mencionadas en un entorno clínico suele ser desarrollado por fisioterapeutas para un propósito específico, basado en la condición de cada paciente (Luan et al., 2019). Las intervenciones de ejercicio generalmente se dividen en programas supervisados realizados en gimnasios y programas de entrenamiento en el hogar (Jansons et al., 2017). Los programas realizados en el gimnasio pueden tener una ventaja sobre los programas realizados en el hogar, al controlar la cantidad y la calidad del entrenamiento de manera directa. Sin embargo, seguir un programa de rehabilitación domiciliaria promueve la adquisición de un papel más activo en los pacientes y mejora la adherencia a la actividad física junto con la adquisición de hábitos de vida más saludables (Humphreys et al., 2014; Jansons et al., 2017; Luan et al., 2019). Entre los diferentes métodos de aplicación de carga en el entrenamiento de resistencia en programas basados en el hogar, las bandas elásticas han demostrado ser efectivas en la rehabilitación del dolor de hombro, cuello, rodilla y cadera (M. S. Rathleff et al., 2014). La rehabilitación domiciliaria es uno de los potenciales beneficiarios de la implantación de bandas elásticas por su bajo precio, adaptabilidad a diferentes entornos y sencilla capacidad de progresar (Andersen et al., 2017; Martín-San Agustín, Laguna Sanz, et al., 2020). Junto con la intensidad, el volumen, y la frecuencia, el tiempo bajo tensión (TUT) es una variable de entrenamiento específica e importante en los ejercicios con bandas elásticas. El TUT total refleja el componente de tiempo de un ejercicio de fortalecimiento y se refiere a la suma de las fases de contracción concéntricas, isométricas y excéntricas (M. Rathleff et al., 2013; M. S. Rathleff et al., 2014, 2015). Investigaciones anteriores sobre programas de rehabilitación con bandas elásticas han propuesto tres escenarios que representan ejercicios de fuerza explosivos, ejercicios de fuerza a una velocidad lenta o ejercicios de fuerza donde no se puede obtener el rango completo de movimiento, del inglés Range of Movement (ROM) (Mcgirr et al., 2015; M. S. Rathleff et al., 2015). A pesar de que los

beneficios de un programa de entrenamiento dependen directamente del grado de cumplimiento de la prescripción, el estudio de los TUT prescritos en diferentes ejercicios y escenarios no ha sido evaluado previamente. Además, conocer la tensión (es decir, la intensidad) que realiza la banda elástica también es esencial para una dosificación adecuada. Así, aunque los fabricantes suelen proporcionar valores de tensión según el porcentaje de elongación de la banda elástica, varios autores han demostrado que estos no suelen ser precisos tras un análisis de laboratorio, siendo además de difícil aplicación práctica, la parametrización del ejercicio a través de la tensión generada mediante el grado de estiramiento de la banda elástica (M. S. Rathleff et al., 2014).

1.1 Objetivos

Los objetivos principales de esta tesis son los siguientes:

1. Evaluar la validez y fiabilidad del DiCI, un dispositivo de tracción, para medir la fuerza de la musculatura del hombro en atletas recreacionales y sujetos sintomáticos en un contexto controlado.
2. Evaluar la fiabilidad intra e inter-examinador del DiCI en un contexto clínico.
3. Analizar los TUTs durante diferentes ejercicios y escenarios para evaluar el grado de cumplimiento.
4. Analizar la tensión obtenida durante diferentes ejercicios y escenarios y compararla con los valores predeterminados.

2. Metodología

2.1. Diseño y sujetos.

Se realizaron dos estudios secuenciales y anidados y un estudio paralelo. Todos los estudios fueron realizados en la Facultad de Fisioterapia de la Universidad de Valencia por estudiantes voluntarios de la misma.

El primer estudio fue un estudio descriptivo observacional y transversal en el cual se tomaron medidas de fuerza de abducción y flexión de hombro mediante la dinamometría portátil en condiciones similares en los sujetos que cumplieron los criterios de inclusión. Participaron 83 sujetos divididos en dos grupos. En el grupo de asintomáticos participaron 43 sujetos sanos (29 varones y 14 mujeres) de manera voluntaria (Edad: 22.1 ± 0.47 años, peso: 68.7 ± 13.1 kg y altura: 173.3 ± 9.7 cm) y en el grupo de sintomáticos, en cuyo grupo el síntoma principal era el dolor de hombro, participaron 40 sujetos (28 varones y 12 mujeres) de manera voluntaria (Edad: 49.9 ± 8.1 años, peso: 70.6 ± 14.3 kg y altura: 171.7 ± 9.0 cm). El protocolo experimental fue aprobado por el Comité de Ética de la Universidad de Valencia (H1533739889520).

El segundo estudio siguió un diseño similar, descriptivo observacional y transversal en el cual se realizaron mediciones de fuerza en diversos movimientos de miembro superior e inferior mediante dinamometría portátil entre dos examinadores de diferente sexo. Participaron 40 sujetos sanos (20 varones y 20 mujeres) de manera voluntaria (Edad: 27.3 ± 5.1 años, peso: 66.2 ± 14.2 kg y altura: 170.7 ± 8.7 cm). El protocolo experimental fue aprobado por la Comité de Ética de la Universidad de Valencia (H1533739889520).

El tercer estudio siguió un diseño similar, descriptivo, observacional y transversal. En este estudio se evaluaron los tiempos bajo tensión y los valores de fuerza en diversos escenarios para la abducción de hombro y extensión de rodilla realizados ambos movimientos con bandas elásticas. Participaron 29 sujetos sanos (24 varones y 5 mujeres) de manera voluntaria (Edad: 23.6 ± 2.9 años, peso: 75.8 ± 11.3 kg y altura: 176.4 ± 6.6 cm). El protocolo experimental fue aprobado por la Comité de Ética de la Universidad de Valencia (1239215).

Existieron criterios comunes de inclusión tales como: (a) edad entre 18 y 30 años, (b) no operados quirúrgicamente de la extremidad superior/inferior, (c) sin dolor del miembro en los 2 meses anteriores a la recolección de datos, (d) realización de ejercicio físico un mínimo de 90 minutos por semana y (e) capaz de proporcionar consentimiento informado por escrito. En el caso del primer estudio, los sujetos incluidos dentro del grupo sintomático fueron incluidos cumpliendo únicamente el criterio de (a) Haber sufrido dolor en la extremidad a evaluar ≥ 3/10 en reposo en la Escala Visual Analógica del dolor (EVA) durante más de tres semanas antes de la inclusión.

2.2. Procedimientos.

2.2.1. Metodología de la evaluación

El uso de la DMP de tracción consiste en la aplicación de una galga extensiométrica para la evaluación de la fuerza isométrica. El funcionamiento de la misma como resistencia variable por la deformación permite su uso dentro del contexto de la evaluación de la fuerza, al asociar esa deformación a un esfuerzo mecánico cuyo valor pretendemos calcular (Figura 1).

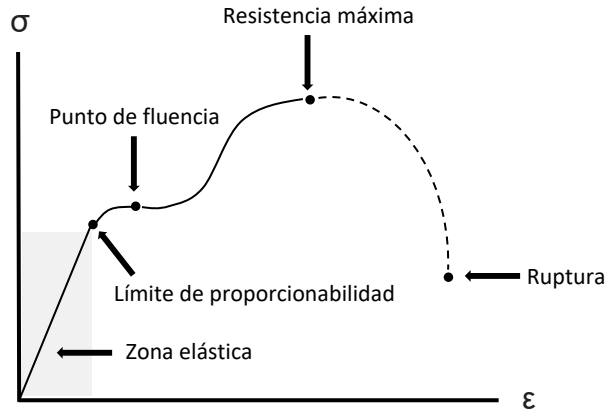

Figura 1. Representación gráfica de la relación entre la tensión mecánica (σ) y la deformación (ε). Fuente: Elaboración propia basada en (Garcia-Casado, 2010).

Para llevar a cabo una evaluación a través de un dispositivo DMP portátil de tracción se realizará una puesta en tensión progresiva de dos puntos separados entre sí, uno, perteneciente al sujeto y miembro a evaluar, y otro al dispositivo DMP, ambos conectados a su vez a través de un elemento de fijación (p.ej. un cinturón rígido).

Cuando se inicia el movimiento, se pone en tensión el sistema de fijación que conecta el dispositivo con el sujeto, produciéndose una deformación parcial de la galga extensiométrica. Esta deformación va a ser proporcional a la fuerza desarrollada por el sujeto y debe ser inferior al límite de proporcionalidad, o encontrarse dentro de la zona elástica de deformación del material al que se encuentra unida la galga extensiométrica, normalmente una celda de carga (Figura 2). La estimulación mecánica de la galga extensiométrica, que se encuentra actuando como resistencia a esa fuerza de tensión generada por el sujeto, se va a traducir a su vez en un estímulo eléctrico, y este en un valor numérico (Ej. Newtons) pudiendo cuantificar de esa manera un esfuerzo mecánico a través de la deformación provocada dentro del sistema de la galga extensiométrica (Garcia-Casado, 2010).

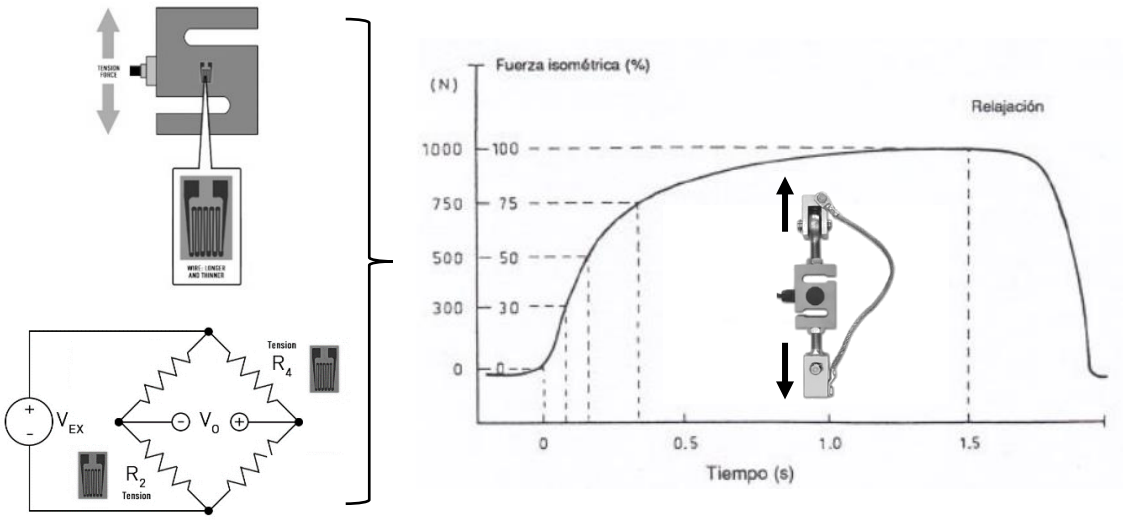

Figura 2. Representación gráfica de la evaluación mediante el uso de un dispositivo de DMP y gráfica obtenida con los distintos parámetros. Fuente: Elaboración propia basada en (Garcia-Casado, 2010).

En la evaluación a través de la DMP, el objetivo principal es conocer la fuerza isométrica máxima (FIM) a través de la realización de una activación muscular máxima progresiva contra una resistencia insalvable. Los déficits en la manifestación de la FIM son considerados un factor de riesgo en la aparición de ciertos tipos de patología, tanto en el miembro superior como en el miembro inferior (FAPTA, 2001; Struyf et al., 2015). Con una contracción muscular muy rápida, tratando de alcanzar la máxima fuerza en el menor tiempo posible, podemos conocer también parámetros como la fuerza explosiva

máxima o la máxima producción de fuerza por unidad de tiempo. Por otro lado, la fuerza medida a través de un dispositivo tipo DMP puede ser calculada de manera dinámica si se utilizan elementos elásticos como bandas elásticas, un implemento comúnmente utilizado en el entrenamiento deportivo o terapéutico (Andersen et al., 2017). El análisis de la fuerza muscular dinámica mediante gomas elástica nos permite obtener valores objetivos de la resistencia que ofrecen las bandas elásticas ante su estiramiento, siendo esta un factor fundamental dentro de los parámetros de cuantificación de la carga en la prescripción de ejercicio (Badillo & Ayestarán, 2002). Además de la resistencia, el tiempo que un determinado esfuerzo se prolonga en el tiempo también es un parámetro que condiciona la carga total del ejercicio prescrito (McArdle et al., 2010). Dentro del trabajo con bandas elásticas, TUT es considerado un valor fundamental para la cuantificación de la carga total de entrenamiento(Andersen et al., 2017; M. Rathleff et al., 2013). La metodología mediante la cual se puede realizar el cálculo de la fuerza dinámica es similar a la evaluación de la FIM. El valor obtenido de la puesta en tensión entre dos puntos es considerado como la resistencia ofrecida por la banda elástica en respuesta a la puesta en tensión producida por el sujeto, en cada momento y fase del movimiento(M. Rathleff et al., 2013).

Figura 3. Evaluación mediante el uso de galga de fuerza para el cálculo de la resistencia ofrecida por la banda elástica en todo el rango de movimiento y los TUT en un ejercicio de extensión de cuádriceps. Fuente: Elaboración propia.

A diferencia de la evaluación de la fuerza, la evaluación de parámetros temporales requiere de la adición de un dispositivo externo sincronizado con el dispositivo DMP, llamado encoder lineal. Se utilizan dentro del contexto

clínico/deportivo para llevar a cabo mediciones directas y continuas del espacio recorrido por una carga externa (barras, pesas, mancuernas, etc.), registrando el tiempo durante el que se produce dicho desplazamiento. A través de la evaluación de la aceleración y velocidad del movimiento, el dispositivo proporcionará valores objetivos que permitirán entre otros, cuantificar el tiempo que el sujeto pasa en cada fase del movimiento, conocidos como: TBT isométrico (fase isométrica del movimiento) en la que la velocidad del movimiento es igual a 0; TBT concéntrico o excéntrico (fase isotónica del movimiento) en la que la velocidad del movimiento es positiva o negativa respectivamente; y TBT total (suma de los tiempos isométricos e isotónicos).

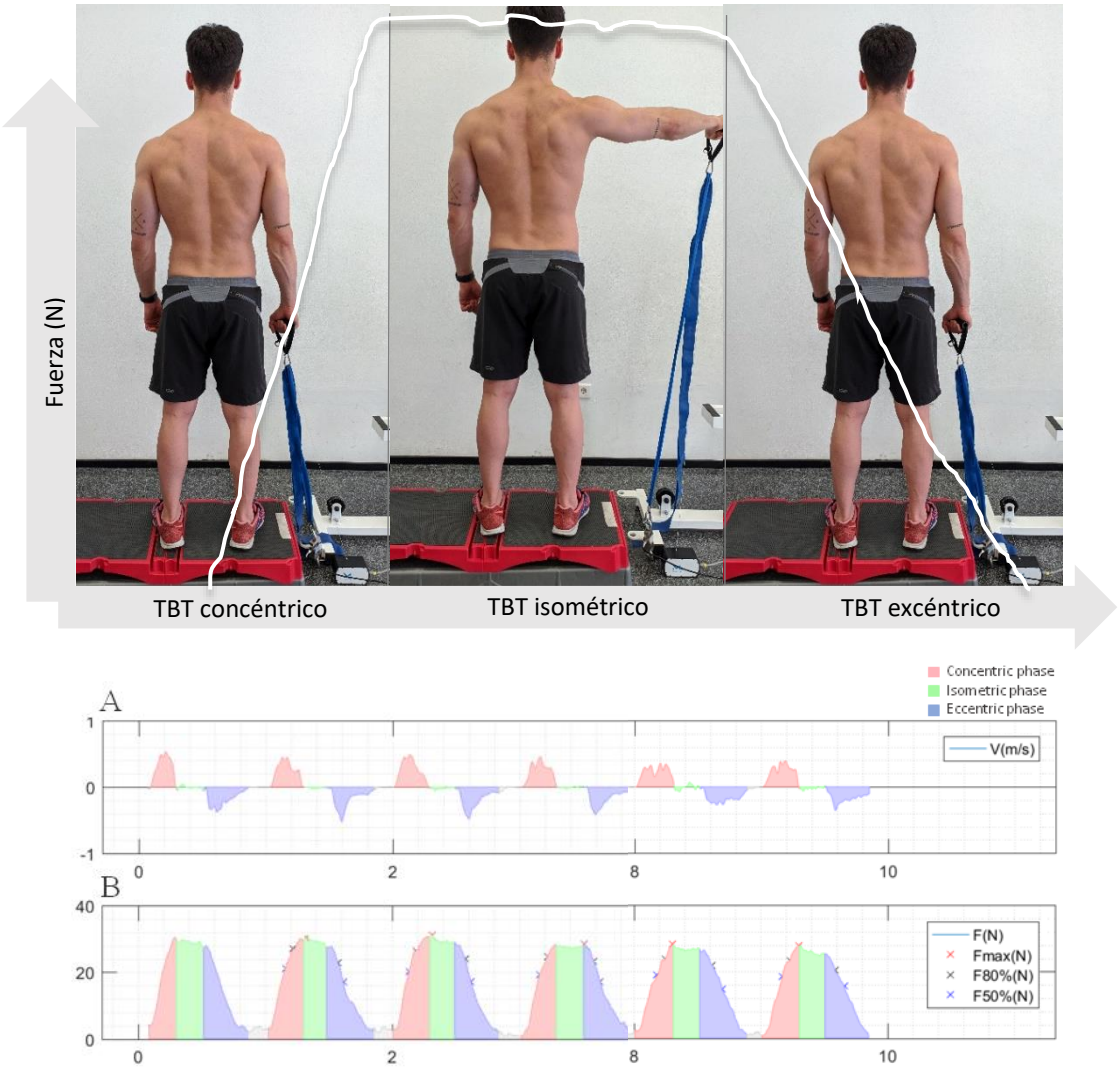

Figura 4. Configuración para el uso de galga de fuerza y encoder lineal, y gráfica que representa la evolución de los parámetros de fuerza con respecto al tiempo. Fuente: Elaboración propia.

El análisis combinado de la fuerza isométrica (FIM) y la fuerza dinámica permite conocer con exactitud parámetros de activación voluntaria en la evaluación muscular. Además, el análisis de parámetro temporales (TBT) nos permite relacionar la expresión de la FIM y la fuerza dinámica con su desarrollo a lo largo del tiempo. Concretamente, el análisis de los TBT parciales y totales nos permite cuantificar el tiempo en cada fase del movimiento, el tiempo total del esfuerzo y, si estos, se ajustan a valores esperados, pudiendo cuantificar de tal manera el adecuado o inadecuado grado de cumplimiento y adherencia al tratamiento de los sujetos evaluados (M. S. Rathleff et al., 2014, 2015).

2.2.2. Recolección de datos

Los participantes fueron instruidos antes del día de las mediciones para cumplir con las siguientes pautas: (a) no participar en ningún ejercicio vigoroso durante las 48 horas previas a la prueba, (b) no consumir bebidas energéticas o suplementos en las 48 horas anteriores a la prueba, (c) no consumir cafeína o alcohol 3 horas antes de la prueba y (d) no comer alimentos 2 horas antes de la prueba. Además, previo al comienzo del estudio, se registraron medidas antropométricas de todos los sujetos, así como la media de min. semanales de práctica deportiva.

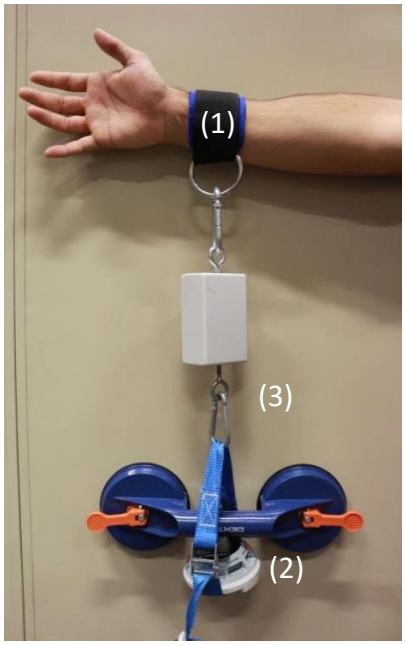

Figura 5. Detalle de la metodología de medición en el movimiento de ABD de hombro a 90º. Fuente: Elaboración propia

En el primer estudio fue evaluada la FIM de los grupos musculares abductores y flexores de hombro, ambos en las posiciones de 45° y 90° con el fin de obtener valores de validez y fiabilidad del dispositivo DiCI, un dispositivo DMP de tracción, comparándolos a su vez con los del MicroFET2 (Hoggan Health Technologies Inc., Salt Lake City, UT) un DMP de compresión que actúa como dispositivo de referencia (Stark et al., 2011). El orden de evaluación entre grupos de flexión y abducción y los grados fue aleatorizado. Para llevar a cabo las evaluaciones, los dispositivos DMP fueron fijados en serie y de manera perpendicular a un anclaje en forma de ventosa doble (Figura 5) con asa Dexter (Dexter Construction; Rocky

Lake Drive, Bedford, Nova Scotia) que se utilizó para estabilizar la medición. El orden específico de colocación fue: (1) La muñeca del sujeto evaluado, sujeta por una muñequera sobre la estiloides del radio (Bohannon, 1997; Wikholm & Bohannon, 1991); (2) El dispositivo Microfet2 unido al anclaje a través de un cinturón rígido; (3) El dispositivo DiCI unido en serie con el Microfet2 a través del cinturón rígido y conectado con el sujeto mediante la muñequera.

La colocación de la posición del sujeto se realizó en base a referencias bibliográficas previas (Bohannon, 1997; Donatelli et al., 2000; Hayes et al., 2002). Para estandarizar la posición de medición los sujetos se colocaron en bipedestación, de manera relajada, con una buena alineación de la espalda, las piernas en extensión y los brazos en posición anatómica a lo largo del cuerpo. El posicionamiento se llevó a cabo a través de un goniómetro de plástico, con intervalos de 1 grado. Se tomó de referencia un punto fijo en la articulación glenohumeral y el segmento libre delimitó el intervalo de trabajo. Se realizó el proceso de posicionamiento de manera individual previo a la medición y se colocaron marcas, también de manera individual que permitiesen realizar el posicionamiento de manera sencilla en caso de perder la referencia previamente realizada.

Dada la alta implicación de sinergias musculares que intervienen en el movimiento de la articulación del hombro se explicó a los sujetos que debían intentar realizar la mayor fuerza posible con el hombro evitando compensar un déficit de fuerza en dicha articulación mediante otros movimientos (Ej. Lateralizar el cuerpo, flexionar el codo, etc). Los sujetos asintomáticos realizaron los test con su brazo dominante, mientras que los sintomáticos lo hicieron con el brazo afecto. Todos los sujetos fueron evaluados con el codo en prono-supinación neutra, con la premisa de "el dedo gordo debe estar apuntando hacia el techo".

Antes de comenzar con la evaluación, se prescribió un calentamiento que consistió en la realización de ejercicios de movilidad articular en flexión y abducción de hombro y tres contracciones isométricas submáximas para cada posición (Leggin et al., 1996).

Dado que nuestro objetivo principal fue la evaluación de la FIM, el comienzo del test se realizó de manera progresiva. Se colocó a los sujetos en la posición idónea, se les pidió que iniciaran el movimiento lentamente para evitar sacudidas y movimientos bruscos y una vez hubiesen adoptado la posición ideal y habían dado tensión a todo el sistema de medición se les pidió que realizaran la máxima fuerza posible durante 5 segundos. Se animó a los sujetos durante la realización de los test, evitando mensajes confusos como: "tira", "empuja" o "vale". Se proporcionaron mensajes estandarizados como: "vamos", "sigue" y "basta"(*Giving feedback | The BMJ*).

Para cada grupo muscular y posición, los sujetos realizaron tres contracciones isométricas voluntarias máximas (CIVM) de cinco segundos, con 60 segundos de descanso entre repeticiones y cinco minutos de descanso entre cada test. Los participantes fueron instados a realizar el máximo esfuerzo y recibieron estímulo oral para mantener la fuerza realizada. Bajo las mismas condiciones que la primera sesión, los test fueron repetidos por el mismo examinador en la segunda sesión con un intervalo de descanso entre sesiones de una semana. Para prevenir la influencia de la sintomatología de los sujetos sintomáticos en la fiabilidad del dispositivo, la segunda medición se realizó tras una hora de descanso después de la primera medición (Hayes et al., 2002).

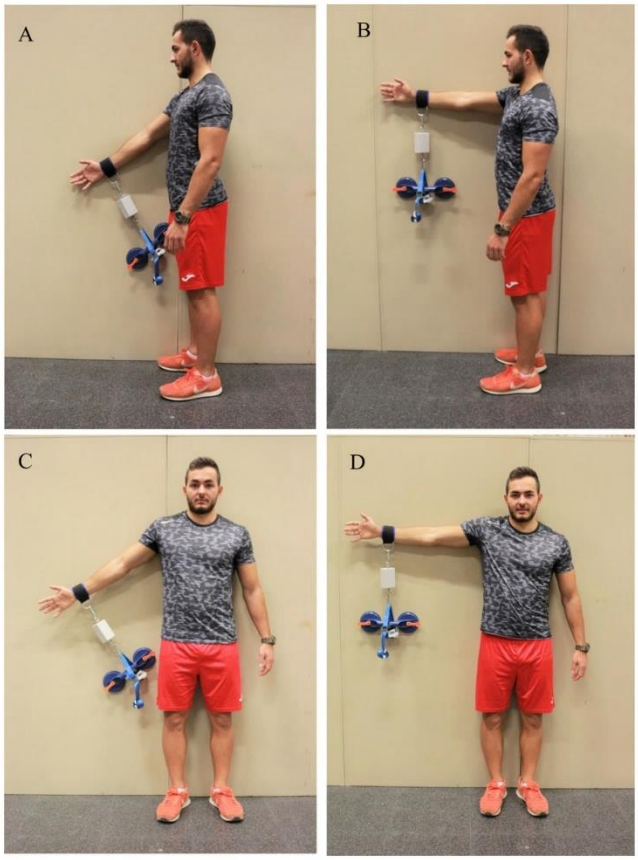

Figura 6. Test isométricos para: (A) Flexión de hombro a 45º; (B) Flexión de hombro a 90º; (C) Abducción de hombro a 45º; (D) Abducción de hombro a 90º.

Dada la posible influencia de la fuerza del examinador en la validez de los resultados en la evaluación de la fuerza (Schrama et al., 2014), en el segundo estudio se realizaron mediciones para evaluar la validez y fiabilidad de la fijación del dispositivo DMP al cuerpo el examinador a través de un cinturón rígido. Además, se realizaron análisis de la fiabilidad Inter-examinador para comparar los valores del dispositivo DMP de presión sin fijación (Figura 7) con el de DMP de tracción (Figura 8). Dichas mediciones se realizaron con dos examinadores y fueron evaluados diversos músculos de los miembros superiores e inferiores que pueden desarrollar diferentes niveles de fuerza.

Antes de realizar las pruebas isométricas, se midieron las características antropométricas de los participantes. Se realizó un calentamiento en una bicicleta con baja resistencia y a velocidad cómoda (80 revoluciones por minuto) durante 10 min y tres contracciones isométricas submáximas para cada posición. Además, estas

contracciones submáximas también se utilizaron para familiarizar a los participantes con la correcta ejecución de las pruebas.

Las pruebas de miembros inferiores se realizaron tanto en posición supina para abducción de cadera (Hip-ABD), aducción de cadera (Hip-ADD), flexión de tobillo (Ank-F) y extensión de tobillo (Ank-E); en la posición prona para la extensión de cadera (Hip-E), rotación de cadera externa (Hip-ER) e interna (Hip-IR); y en la posición sentada para la prueba de flexión de cadera (Hip-F).

Las pruebas de miembros superiores se realizaron en decúbito supino para la flexión del codo (Elb-F) y la extensión (Elb-E), para la flexión del hombro (Sho-F), la extensión (Sho-E) y la abducción (Sho-A), y para la rotación interna (Sho-IR) y externa (Sho-ER) del hombro.

Las pruebas isométricas realizadas tanto para miembros inferiores como superiores fueron seleccionadas dado los pequeños valores de variación en las mediciones que mostraron en estudios previos (Donatelli et al., 2000; M. Rathleff et al., 2013) . El orden de las pruebas se aleatorizó para cada participante para evitar el sesgo sistemático. Se realizaron dos CVIM de 5 s por movimiento con 60 s de reposo entre mediciones. Se aplicó un descanso de 10 min entre las mediciones del evaluador. Los participantes fueron instruidos para realizar el máximo esfuerzo y recibieron indicaciones orales para mantener la fuerza realizada.

Figura 7. Test isométricos con MicroFET2 sin fijación para: (A) Hip-ABD; (B) Hip-ADD; (C) Ank-E; (D) Ank-F; (E) Hip-F; (F) Hip-E; (G) Hip-IR; (H) Hip-IR; (I) Elb-E; (J) Elb-F; (K) Sho-F; (L) Sho-E; (M) Sho-A; (N) Sho-IR; (O) Sho-ER.

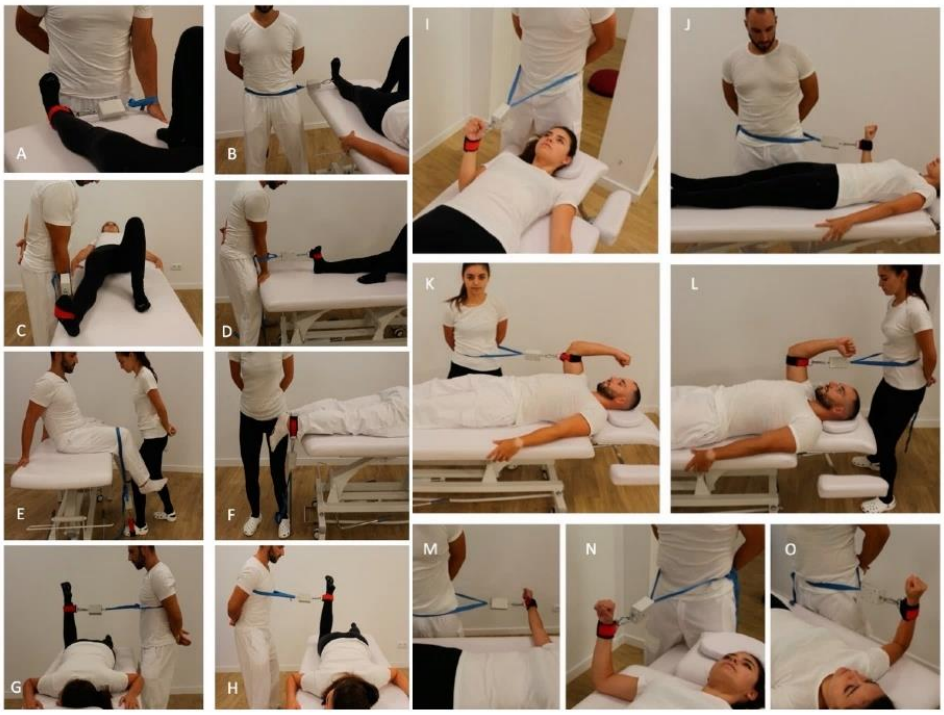

Figura 8. Test isométricos con dispositivo DiCI fijado con cinturón para: (A) Hip-ABD; (B) Hip-ADD; (C) Ank-E; (D) Ank-F; (E) Hip-F; (F) Hip-E; (G) Hip-IR; (H) Hip-IR; (I) Elb-E; (J) Elb-F; (K) Sho-F; (L) Sho-E; (M) Sho-A; (N) Sho-IR; (O) Sho-ER.

A parte de las mediciones de fuerza, en el tercer estudio se evaluaron los TBT y se obtuvieron valores de resistencia ofrecida por las bandas elásticas para compararlas con valores predeterminados ofrecidos por el fabricante. Antes de las mediciones, se solicitó a los sujetos que no participaran en ningún ejercicio extenuante durante las 48 h anteriores. La sesión de evaluación comenzó con un calentamiento estándar, que consistió en subir y bajar varios tramos de escaleras y realizar abducciones de hombro sin peso. La abducción del hombro y la extensión de la rodilla con bandas elásticas se evaluaron en tres escenarios comunes de entrenamiento de bandas elástica: (I) 0–90° a alta velocidad, (II) 0–90° a baja velocidad y (III) 0–45° a baja velocidad (M. S. Rathleff et al., 2014).

Estos escenarios se han propuesto para representar (I) ejercicios explosivos, (II) ejercicios de fuerza tradicionales o (III) ejercicios de fuerza donde no se puede obtener un ROM completo, como a menudo se indica en pacientes con disminución del espacio subacromial. A su vez, cada escenario tiene un tiempo establecido asociado a cada una de las 3 fases de movimiento (concéntrica, isométrica, excéntrica) y un tiempo de descanso entre repeticiones distribuido de la siguiente manera: (I) 1/2/1/1 s, (II) 3/2/3/2 s, y (III) 1.5/2/1.5/2 s. La velocidad de ejecución de cada escenario se proporcionó a los participantes a través de la retroalimentación de un metrónomo. Además, los participantes eran guiados verbalmente si no seguían el ritmo del metrónomo.

Las pautas establecidas para realizar la abducción del hombro se propusieron en base a estudios previos de la siguiente manera: (I) distancia del ancho de la cadera entre los pies, (II) flexión horizontal de 30°, (III) palma mirando hacia el suelo y (IV) ligera flexión del codo (Faber et al., 2015). Para la extensión de la rodilla, los sujetos se sentaron en una máquina de extensión de cuádriceps con una flexión de cadera de 90 ° y una banda elástica perpendicularmente anclada al tobillo cinco cm por encima de los maléolos. El orden de los ejercicios y escenarios se aleatorizó mediante un sistema numérico aleatorio tanto para los ejercicios como para los escenarios.

Las bandas elásticas utilizadas fueron TheraBand CLX (The Hygenic Corporation, Akron, OH, USA). Fueron empleadas una banda azul para abducción de hombro y una dorada dorado para extensión de rodilla. Las bandas tenían una longitud de 40 cm (es decir, 2 asas), siendo utilizadas comúnmente en estudios de rehabilitación (Holmgren

et al., 2012; Kuhn, 2009; Walther et al., 2004). El extremo de la banda elástica se ancló a un mango para facilitar la abducción de hombro o a una tobillera para la extensión de rodilla. Dicho extremo se ancló también a una galga extensiométrica de fuerza (MuscleLab 4020e, Ergotest Technology AS, Porsgrunn, Noruega). Dado que el ejercicio de abducción de hombro generalmente se realiza pisando la banda elástica(Faber et al., 2015; Mcgirr et al., 2015; M. S. Rathleff et al., 2014), los sujetos se colocaron en un escalón para poder desestimar la altura de la galga de fuerza. La velocidad de movimiento y la longitud de elongación de la banda elástica se evaluaron utilizando un encoder lineal (MuscleLab 4020e, Ergotest Technology AS, Porsgrunn, Noruega) anclado al mango o al tobillo.

Los participantes tuvieron dos intentos de familiarización por escenario. Con una ligera tensión de la banda elástica en la posición inicial (es decir, la mínima para evitar arrugas en la banda elástica), los sujetos tuvieron que realizar 2 series de 10 repeticiones por ejercicio y escenario, con 2 min de descanso entre series. La información del encoder lineal y de la galga fue registrada por la Unidad de Sincronización de Datos (DSU) ML6000 que es la unidad donde se conectan e integran los sensores MuscleLab 4020e (MuscleLab 4020e, Ergotest Technology AS, Porsgrunn)(Martín-San Agustín, Sánchez-Barbadora, et al., 2020),

Las fases de movimiento, los TUTs y los parámetros de fuerza se calcularon utilizando la unidad de integración mediante MATLAB (versión R2019b; The Mathworks, Natick, MA, Estados Unidos). La fase del movimiento para cada repetición se determinó a partir de la velocidad: positiva para la fase concéntrica, alrededor de 0 m/s para la fase isométrica, y velocidad negativa para la fase excéntrica. Una vez determinadas las fases, se calcularon los parámetros TUT y fuerza. Los TUT calculados fueron TUT concéntrico, TUT isométrico, TUT excéntrico y TUT total como la suma de TUT concéntrico, isométrico y excéntrico durante 1 repetición. Los parámetros de fuerza analizados (Newton) fueron la tensión al 50% y el 80% en cada fase (medida como el 50% y el 80% de la elongación máxima de cada fase) y la tensión máxima obtenida. Se calcularon las medias a través de las 10 repeticiones para cada parámetro. Además, se calculó la fuerza máxima estimada para cada ejercicio y escenario, teniendo como referencia la información proporcionada por el fabricante (Sarda, 2006). El alargamiento de la banda elástica se

calculó restando la longitud inicial en reposo (es decir, 40 cm) de la longitud de la banda elástica al final de la ROM (medida con el codificador lineal).

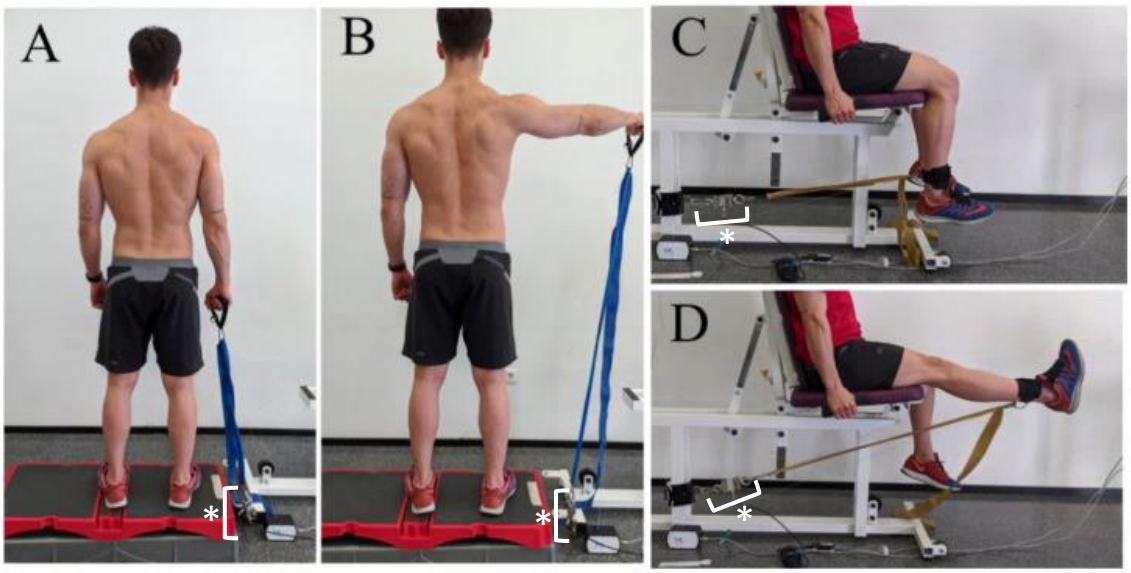

Figura 9. Configuración de la abducción de hombro (A,B) utilizando la galga de fuerza anclada al extremo de la banda elástica y un encoder lineal para evaluar la velocidad y la elongación. Configuración de la extensión de rodilla (C,D) utilizando la misma metodología. Inicia y termina en flexión de cadera y rodilla de 90º y el punto de máxima tensión se alcanza en la extensión completa de rodilla. (*) = Galga de fuerza (cm desestimados en la estimación de tensión)

2.3. Análisis estadístico.

Se utilizó el software SPSS 24 para Windows (SPSS Inc., Chicago, IL, EEUU) para realizar el análisis estadístico y MedCalc Statistical Software (MedCalc Software, Mariakerke, Belgium) para generar los gráficos de Bland-Atlman. La normalidad de las variables fue comprobada mediante la prueba de Kolmogorov-Smirnov y la homogeneidad de las variaciones con la prueba de Levene. Los valores son presentados mediante sus medias, desviaciones estándar (DE) e intervalos de confianza (IC). Para la obtención de los valores se utilizó la media de tres repeticiones.

Para el análisis de la validez concurrente entre los dispositivos DMP (DiCI y MicroFet2), se calculó el coeficiente de correlación de Pearson (*r*), junto a sus intervalos de confianza del 95% (95% IC) y se utilizaron diagramas de Bland-Altmann.

Se calcularon además para el dispositivo DMP de tracción, los límites superior e inferior del acuerdo (LoA), la media, y la desviación estándar de la diferencia entre los DMP (tanto con diferencia absoluta como en porcentajes) en comparación con los valores de MicroFet2. Los gráficos Bland-Altmann muestran gráficamente la diferencia promedio entre mediciones en las cuales se compara la interacción entre test - retest, y el 95% del límite de acuerdo (LoA). El 95% LoAs fue calculado como LoA = sesgos ± 1.96 DE, indicando como término sesgos la diferencia promedio entre los métodos de medición

La fiabilidad relativa fue calculada mediante el coeficiente de correlación intraclase (ICC) y la absoluta, expresada mediante el error estándar de medida (SEM), y el mínimo cambio detectable (MDC). La fiabilidad fue clasificada como excelente (ICC > 0.90), buena (ICC=0.76–0.90), moderada (ICC=0.51–0.75), y baja (ICC <0.50)(Koo & Li, 2016).

El MDC fue calculado para el 95% IC como MDC_{95} = SEM x 1.96 x √2, donde SEM=SD √(1 – ICC). Los valores del SEM y el MDC también fueron expresado como SEM% y MDC%, dividiendo el SEM y el MDC con el promedio de los valores del test (Atkinson & Nevill, 1998; Riemann & Lininger, 2018).

En el segundo estudio, el programa MATLAB (versión R2019b; The Mathworks, Natick, MA, USA) fue utilizado para realizar todos los análisis estadísticos por un investigador cegado durante mediciones.

Para el análisis de la fiabilidad, se calcularon valores de: (1) fiabilidad relativa a través del ICC y (2) fiabilidad absoluta a través del SEM. Como en el estudio anterior, la fiabilidad relativa se consideró como excelente (ICC > 0.90), buena (ICC=0.76–0.90), moderada (ICC=0.51–0.75), y baja (ICC <0.50) (Koo & Li, 2016). El SEM, para la fiabilidad absoluta se calculó como SEM = SD √(1 – ICC).

Para el análisis del acuerdo entre las evaluaciones de fuerza entre los dos examinadores con diferentes características antropométricas, y con el objetivo de analizar posibles errores sistemáticos en las mediciones entre ambos examinadores se realizó una prueba T para muestras relacionadas. Además, se calcularon las diferencias

entre los examinadores para cada método y se compararon utilizando de nuevo una prueba T para muestras relacionadas, obteniendo una $p < 0.05$.

El tamaño de la muestra fue calculado mediante la fórmula para estudios de fiabilidad basada en los intervalos de confianza (Streiner et al., 2014). Con un número de participantes (k) igual a 2, el intervalo alrededor de r (coeficiente de fiabilidad) de 0.05, y una r estimada de 0.95, el tamaño de la muestra (n) obtenido fue de 25 participantes. De cualquier modo, se incluyeron 15 personas más a la muestra para aumentar el poder del proyecto

El grado de cumplimiento de los TUTs esperados por fase y total se analizó por sujeto y repetición, considerando el TUT obtenido como 'cumplido' siempre que el error fuera inferior al 10% con respecto al TUT prescrito. Los TUT de las repeticiones se situaron en el rango, excedieron el TUT prescrito o no alcanzaron el TUT prescrito.

Se utilizó una prueba T de medidas relacionadas para analizar las diferencias entre la fuerza máxima obtenida y la fuerza máxima estimada por escenario y ejercicio, y se calculó la d de Cohen para evaluar el tamaño del efecto ($d > 0,2$: trivial, 0,2–0,5: pequeño, 0,5–0,8: mediano y >0,8: grande)

3. Resultados

Las comparaciones entre los dispositivos DICI y Microfet2 para las mediciones de fuerza de los movimientos de flexión y abducción de hombro a 45º y 90º mostraron una gran correlación (*r*'s = 0.997-0.998). Además, ambos dinamómetros ofrecieron unos valores de acuerdo casi perfectos con pequeños "sesgos" (entre 0.30% hasta 0.99%) e "imprecisión" (entre 2.24% y 2.35%). La fiabilidad relativa mostró excelentes resultados tanto para las mediciones en sujetos asintomáticos (ICC's = 0.96 - 0.97) como sintomáticos (ICC's = 0.94 – 0.97). En cuanto a la fiabilidad absoluta los análisis mostraron valores de SEM < 2.18% y MDC < 6.33N en sujetos asintomáticos y valores de SEM <2.25% y MDC < 3.42N en sujetos sintomáticos.

Las comparaciones intraexaminador, tanto intra como intersesión, mostraron una validez y acuerdo excelentes (ICC's = 0.995 – 0.998) para todos los test realizados tanto en miembro superior como inferior con el dispositivo de tracción DICI. Los valores de SEM fueron en ambos escenarios inferiores al 1%. En la comparación entre examinadores los valores de ICC fueron excelentes (ICC's > 0.991) y los valores de SEM inferiores al 1%. El acuerdo entre examinadores mostró diferencias entre ambos que oscilaba entre el -0.69% hasta el -3.78%, siempre en favor del examinador 1 (varón). Para algunos movimientos como la abducción/aducción de cadera y las rotaciones de cadera, tanto el DICI como el Microfet2 mostraron diferencias entre examinadores menores a 20 N (Entre 0.20% y 0.89% en el DICI; entre 0.26% y 1.59% en el Microfet2). Por otra parte, en otros movimientos como la flexión de cadera, la flexión de tobillo y la extensión de hombro, ambos métodos mostraron diferencias más evidentes entre examinadores, siendo estas diferencias mayores en el caso del Microfet2 (3.61%, 3.78% y 2.84% para el DICI; 9.68%, 12.91% y 9.71% para el Microfet2 respectivamente). Los diagramas de Bland Altman muestran que para valores mayores de 200N, las diferencias entre examinadores aumentan progresivamente con el Microfet2, mientras que con el DICI se mantienen estables.

El examen de los TUTs mostró diferencias en cuanto al grado de cumplimiento de cada uno de los ejercicios. En cuanto a la abducción de hombro, los tres escenarios mostraron un mejor grado de cumplimiento en las fases concéntrica e isométricas del

movimiento en comparación con la fase excéntrica. Los valores del escenario de abducción rápida y lenta fueron los que mostraron un mayor grado de cumplimiento, siendo el escenario con una restricción del ROM el que mostró valores de cumplimiento menores a los dos escenarios previos. Las repeticiones que se encontraron fuera del grado de cumplimiento en los dos primeros escenarios tendieron a ser realizadas en un menor tiempo del esperado (179/580; 30.9% para la abducción rápida y 136/580; 23.4% para la abducción lenta). En el escenario con restricción del ROM, la tendencia fue la opuesta, la mayor parte de las repeticiones fuera del grado de cumplimiento se realizaron en un tiempo mayor del esperado (235/580; 40.5%). El grado de cumplimiento de los TUT para la extensión de rodilla siguió un comportamiento similar a la abducción de hombro. Los escenarios de extensión rápida y lenta de rodilla mostraron mejor grado de cumplimiento en su fase concéntrica e isométrica en comparación con la fase excéntrica, que mostró un grado de cumplimiento menor. De igual modo, el escenario con restricción del ROM mostró un grado de cumplimiento ligeramente inferior a los dos escenarios previamente mencionados. En ambos ejercicios los TUTs totales mostraron valores elevados en comparación con los valores más bajos obtenidos por fases de movimiento (536/580; 92.4%, 410/580; 70.7%, 340/580; 58.6% para el escenario de abducción rápida, lenta y restringida respectivamente; 520/580; 89.6%, 299/580; 51.5% para el escenario de extensión rápida y restringida de rodilla respectivamente).

Por último, la comparación entre la fuerza obtenida y los valores estimados para la abducción de hombro y la extensión de rodilla mostró diferencias entre ejercicios y escenarios, entre la máxima fuerza estimada y la máxima fuerza obtenida. Todos los valores de fuerza obtenidos fueron inferiores a los valores esperados, oscilando estas diferencias entre 34.1% y 38.5% para los escenarios de abducción de hombro y 24.8% y 29.5% en los escenarios de extensión de rodilla.

4. Conclusiones

1. El DiCI ha demostrado ser válido y confiable para evaluar la abducción del hombro y la fuerza de flexión a 45° y 90° en sujetos asintomáticos y sintomáticos.

2. La fijación del DiCI mostró una excelente fiabilidad y un acuerdo aceptable entre las mediciones de los examinadores, que tenían un cuerpo y un perfil de fuerza diferentes. Además, en comparación con el método tradicional de medición de la fuerza con DMP, empujando contra la mano del examinador, el método de tracción mostró un mejor acuerdo entre los examinadores, especialmente para aquellas pruebas que mostraron altos niveles de fuerza.

3. Los ejercicios y escenarios analizados demostraron un menor grado de cumplimiento en la fase excéntrica que en las fases concéntrica e isométrica. El TUT total no parece ser un valor recomendable para la evaluación ya que puede enmascarar lo sucedido en las diferentes fases del movimiento.

4. Además, el análisis de fuerza para las bandas elásticas utilizadas en nuestro estudio reveló que los valores descritos por el fabricante muestran una tendencia a estar sobreestimados.

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Anexos

Categorización de los artículos presentados en la tesis doctoral

Artículo	Revista	Factor de impacto (según JCR)	Área temática	Ranking	Cuartil
I	Peer J	3.06	Multidisciplinary sciences	33/74	Q2
II	MDPI (Diagnostics)	3.992	Medicine, General & Internal	60/172	Q2
III	MDPI (Diagnostics)	3.992	Medicine, General & Internal	60/172	Q2

JCR: Journal Citation Reports (2021).

ARTÍCULO I

González-Rosalén J, Cuerda-Del Pino A, Sánchez-Barbadora M, Martín-San Agustín R. (2021). Validity and reliability of the DiCI for the measurement of shoulder flexion and abduction strength in asymptomatic and symptomatic subjects. PeerJ 9:e11600. doi: 10.7717/peerj.11600

Validity and reliability of the DiCI for the measurement of shoulder flexion and abduction strength in asymptomatic and symptomatic subjects

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ABSTRACT

Background. A higher risk of shoulder injury in the athletic and non-athletic population is frequently associated with strength deficits. Therefore, shoulder strength assessment can be clinically useful to identify and to quantify the magnitude of strength deficit. Thus, the aim of this study was to evaluate the validity and reliability of a DiCI (a new hand-held dynamometer) for the measurement of shoulder flexion and abduction strength in asymptomatic and symptomatic subjects.

Methods. Forty-three recreational athletes (29 males and 14 females; age: 22.1 ± 0.47 years; body mass: 68.7 ± 13.1 kg; height = 173.3 ± 9.7 cm) and 40 symptomatic subjects (28 males and 12 females; age: 49.9 ± 8.1 years; body mass: 70.6 ± 14.3 kg; height = 171.7 ± 9.0 cm) completed shoulder flexion and abduction strength tests in two identical sessions one-week apart. Both types of movement were evaluated at 45º and 90º.

Results. Relative reliability analysis showed excellent intra-class correlation coefficients (ICC) for all evaluated movements (ICC range = 0.90 to 0.99). Absolute reliability analysis showed a standard error of measurement (SEM) ranging from 1.36% to 2.25%, and minimal detectable change (MDC) ranging from 3.93% to 6.25%. In conclusion, the DiCI is a valid and reliable device for assessing shoulder strength both in recreational athletes and in subjects with restricted mobility and loss of strength.

Subjects Anatomy and Physiology, Drugs and Devices, Kinesiology, Orthopedics, Rheumatology
Keywords Hand-held dynamometer, Shoulder, Validity/reliability, Symptomatic

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Additional Information and Declarations can be found on page 9

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INTRODUCTION

Shoulder injuries and pain can lead to major disability, activity restrictions, as well as limiting participation in basic life areas such as work, education, and socialization (*Hopman, Lukersmith & Krahe, 2013*). Previous research has established that a higher risk of shoulder injury in the athletic and non-athletic population is frequently associated with strength deficits (*Tyler et al., 2005*; *Whiteley et al., 2012*; *Edouard et al., 2013*). Even though strength deficits are considered as a sign related with shoulder pain, muscle weakness itself has been associated with a higher risk of developing secondary disorders such as rotator cuff pathology (*Celik, Dirican & Baltaci, 2012*; *Struyf et al., 2015*). Thus, the lack

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of strength seems to play an important role in the development of pathologies such as subacromial impingement syndrome (SIS) (*Celik, Dirican & Baltaci, 2012*), rotator cuff injuries (*Ellenbecker & Cools, 2010*), and glenohumeral joint instability (*Wilk, Macrina & Reinold, 2006*). Moreover, strength deficits may perpetuate injuries in which an altered movement pattern leads to excessive loading of the tissues (*Struyf et al., 2015*). Therefore, shoulder strength assessment can be clinically useful (*Struyf et al., 2015*; *Maestroni et al., 2020*).

Isokinetic and hand-held dynamometers (HHDs) are often used for objectively measuring strength in a clinical setting, being both valid and reliable tools for isometric strength measurement of the shoulder muscles (*Stark et al., 2011*). Whereas isokinetic dynamometers are costly and difficult to transport, HHDs are portable, less expensive, and easier to use (*Stark et al., 2011*). For this reason, they have been established as the most commonly used method in isometric strength measurement (*Schrama et al., 2014*). Even so, other limitations are related to the use of HHDs, such as the absence of stabilization and the influence of examiner strength (e.g., male/female) on the obtained values (*Kolber & Cleland, 2005*; *Schrama et al., 2014*). To solve this problem, HHDs have been secured in subsequent studies, removing the influence the examiner's strength (*Kolber et al., 2007*; *Katoh, 2015*; *Romero-Franco, 2019*).

HHD stabilization has been carried out following two different methodologies: first, using a push HHD fixed with a strap or a belt, and second, using a pull-type portable dynamometer. The stabilized push HHD represents the most common option used in previous studies for measuring isometric strength (*Schrama et al., 2014*). The subject applies force to the push HHD which is attached to a belt and fixed to an anchorage. The subject pushes the HHD and generates movement by traction between the HHD and the stabilization. Evaluations with fixed push HHDs have been proposed for quantifying rotator cuff strength (*Kolber et al., 2007*) or shoulder joint muscle strength (*Katoh, 2015*). Since traction is defined as the action of pulling on something, the use of a pull-type HHD is perhaps more convenient in isometric strength assessment. Recently, the validity and reliability of a low-cost pull-type device, developed with other expected uses (i.e., weigh fish), has been analysed for the movements of the upper limbs (*Romero-Franco, 2019*). In this way, other pull-type HHDs, like DiCI (from the Spanish 'Dispositivo de Control de Intensidad,' or Intensity Control Device), have been developed to be used in strength assessment by clinicians and performance professionals. This HHD measures the traction strength through two hooks in series and it has its own software that allows the values to be recorded in a clinical history model (*Martín-San Agustín et al., 2020*). While the DiCI has been validated to measure lower limb strength in healthy subjects (*Martín-San Agustín et al., 2020*), other regions such as the shoulder and its use in patients have not yet been studied. Therefore, the purpose of this study was to evaluate the validity and reliability of the DiCI for the strength measurement of shoulder muscles, both in recreational athletes and symptomatic subjects.

MATERIALS & METHODS

Study design

In order to assess the concurrent validity and intra-rater reliability of the DiCI, an observational study was conducted. For this purpose, an examiner evaluated the subjects in two sessions, spaced one-week apart for asymptomatic participants and with 1-h interval between measurements (to minimize the influence of their changes in symptoms on the device's reliability) for symptomatic participants (*Cánovas-Ambit et al., 2021*). for asymptomatic subjects and with one-hour interval between measurements for symptomatic subjects. All of them underwent an evaluation of shoulder abduction and flexion strength.

Subjects

43 recreational athletes and 40 symptomatic subjects voluntarily participated in the study. Subject were recruited both by email using the University of Valencia Intranet and through advertising at the Blasco Ibañez Campus of the University of Valencia. The specific inclusion criteria for the asymptomatic subjects were: (1) age between 18 and 30 years; (2) not having undergone a surgical intervention on the upper limb; (3) not having suffered pain episodes in the upper limb two months before data collection; (4) a minimum of 90 of physical activity minutes per week. Symptomatic subjects were included if they reported an average pain value of $\geq$ 3/10 at rest in a Visual Analog Scale lasting more than 3 weeks (*Martín-San Agustín et al., 2019*). All participants received a detailed explanation of the study procedures and signed informed consent. The study was approved by the research ethics committee of the University of Valencia (H1533739889520). The examiner was a physical therapist with more than 2 years of experience in muscle strength assessment with HHDs.

Procedures

Anthropometric characteristics were collected before the tests began. Participants were instructed to perform warm-up mobility exercises (15 repetitions of shoulder flexion and abduction) and three submaximal isometric contractions for all positions (*Leggin et al., 1996*).

Validity was assessed in the first session only for asymptomatic subjects by comparing the values simultaneously obtained using the DiCI (Ionclinics S.L, L'Alcudia, Spain) and the reference measure, the MicroFET2 (Hoggan Health Technologies Inc., Salt Lake City, UT) (*Stark et al., 2011*; *Martín-San Agustín et al., 2020*). Both HHDs are battery operated, with a maximum peak force of 1320N for the MicroFET2 and 1200N for the DiCI. Measures on the first and second sessions were compared to obtain test-retest reliability in both groups.

Strength testing and data collection for the two HHDs were carried out simultaneously (*Martín-San Agustín et al., 2020*). The DiCI and the MicroFET2 were fixed in series and perpendicular to a glass suction cup (Dexter Construction; Rocky Lake Drive, Bedford, Nova Scotia) and the arm of the subject. The strap connecting the anchorage on the arm and the devices was placed above the radial styloid process (*Wikholm & Bohannon, 1991*; *Bohannon, 1997*). The specific order for HHD placement was: (1) DiCI attached to the strap, (2) MicroFet2 strapped to the grip of the glass suction cup and connected to the

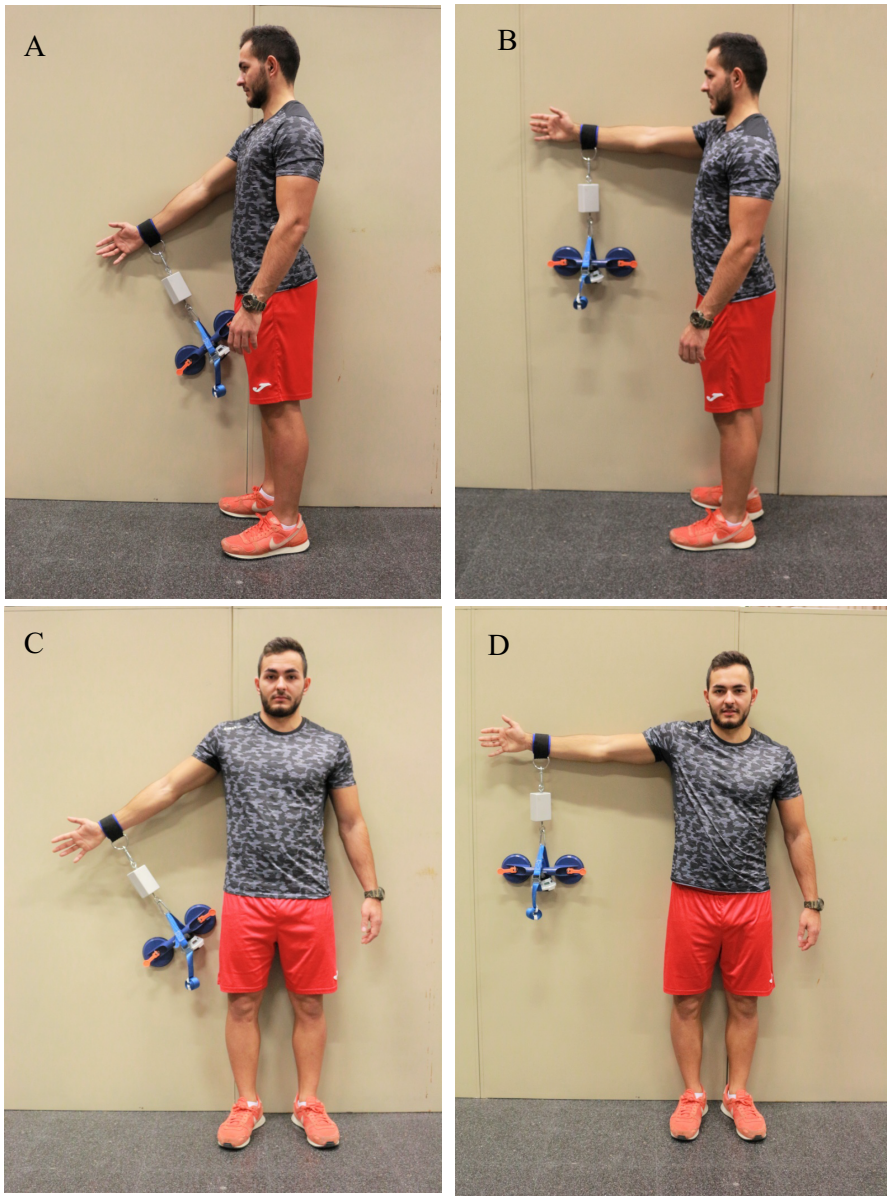

Figure 1 Isometric strength tests for: (A) shoulder flexion at 45°; (B) shoulder abduction at 90°; (C) shoulder abduction at 45°; (D) shoulder abduction at 90°. Photo credit: Rodrigo Martín-San Agustín.
Full-size DOI: 10.7717/peerj.11600/fig-1

DiCI (Fig. 1). Asymptomatic subjects performed the tests with their dominant arm (*Evans, Dressler & Uhl, 2018*) and symptomatic subjects with their affected arm.

The muscle groups evaluated were shoulder flexors and abductors. Both were tested at 45° and 90° in standing position for asymptomatic subjects and at 45° only for symptomatic subjects because patients with shoulder pain usually show limitation to reach 90° of shoulder flexion or abduction (*Martín-San Agustín et al., 2019*). Subjects were positioned prior the strength test. To ensure that the position would remain constant during the evaluation, subjects were instructed to maintain the elbow in full extension, the wrist in neutral

prono-supination, and the thumb of the lifted arm pointing upwards. They were also instructed not to compensate the lack of strength on the target muscles by a lateralization of the trunk or bending the elbow. The order of evaluation was randomized for muscle groups and degrees. Because the effect of gravity can result in measurement errors, the weight of the HHD was dismissed (*Bohannon, 1997*).

For each muscle group, subjects performed three MVIC for 5 s, with 60 s rest between repetitions and 5 min rest between tests. The subjects were asked to perform maximal voluntary isometric contraction (MVIC) at 45° and/or 90° of ROM (*Hayes et al., 2002*). A make-test was carried out by the tester after instructing the subjects to come to a maximum effort over a one- to two-second period and receiving oral stimuli to maintain the strength for three to five seconds until the examiner told them to relax.

Statistical analysis

Participant characteristics and strength values (Newtons) were presented as mean ± standard deviation (SD) or percentages, as appropriate. The mean between the three repetitions was used for analyses.

For the analysis of the concurrent validity and agreement between the HHD measurements (DiCI and MicroFet2), Pearson's product-moment correlation coefficient (r) with 95% confidence interval (CI) and Bland-Altmann plots were used. Furthermore: the upper and lower limits of agreement (LoA), the mean, and SD of the difference between HHDs (both with absolute difference and percentages) were calculated in comparison with the MicroFet2 values.

Relative reliability was estimated with intra-class correlation coefficients (ICC), and absolute reliability was calculated with the standard error of measurement (SEM) and the minimal detectable change (MDC). The relative reliability was classified as excellent (ICC > 0.90), good (ICC = 0.76–0.90), moderate (ICC = 0.51–0.75), and poor (ICC < 0.50) (*Koo & Li, 2016*). MDC was calculated for the 95% CI as MDC95 = SEM × 1.96 X $\sqrt{2}$, where SEM = SD$\sqrt{(1-\text{ICC})}$. Both SEM and MDC were also expressed as SEM% and MDC% by dividing the SEM and MDC values respectively by the mean of the values of the test (*Atkinson & Nevill, 1998*; *Riemann & Lininger, 2018*).

SPSS (version 24; SPSS Inc, Chicago, IL) for all analyses and MedCalc Statistical Software (MedCalc Software, Mariakerke, Belgium) to build the Bland-Altman graphs were used.

RESULTS

Subjects

Asymptomatic subjects showed an average of 22.1 years (SD = 3.6), with a body mass of 68.7 kg (SD = 13.1), and a height of 173.3 cm (SD = 9.7). Symptomatic subjects showed an average of 49.9 years (SD = 8.1), with a body mass of 70.6 kg (SD = 14.3), and a height of 171.7 cm (SD = 9.0). The average pain of symptomatic subjects was 4.8 out of 10 (SD = 1.5). The average duration of symptoms of this group was 8.1 weeks (SD = 1.8) (Table 1).

Table 1 Characteristics of the subjects. Date represents mean and standard deviation.

	Asymptomatic ($n = 43$)	Symptomatic ($n = 40$)
Age (years)	22.1 (0.47)	49.9 (8.1)
Body mass (kg)	68.7 (13.1)	70.6 (14.3)
Stature (cm)	173.3 (9.7)	171.7 (9.0)
Body Mass Index (kg/m^2)	22.66 (2.60)	23.77 (3.57)
Gender	Males ($n = 29$)	Males ($n = 28$)
Pain (0–10/10)	0	4.8 (1.5)
Duration of symptoms (weeks)	–	8.1 (1.8)

Table 2 Validity between DICI and MicroFet2 dynamometers for the shoulder strength measurements.

	MicroFet2 (SD)	DICI (SD)	Pearson coefficient	Lo A- (%)	Lo A+ (%)	Mean difference (%)	Standard deviation (%)
Flexion							
90°	95.24 (28.77)	96.20 (28.67)	0.997	−3.44 (3.61%)	5.36 (5.62%)	0.95 (0.99%)	2.24 (2.35%)
45°	104.41 (33.50)	104.74 (33.29)	0.997	−4.45 (4.26%)	5.09 (4.87%)	0.32 (0.30%)	2.43 (2.32%)
Abduction							
90°	95.24 (30.12)	95.59 (29.50)	0.998	−3.86 (4.05%)	4.55 (4.78%)	0.34 (0.36%)	2.14 (2.24%)
45°	100.83 (34.88)	101.15 (34.34)	0.998	−3.55 (3.52%)	4.19 (4.15%)	0.32 (0.32%)	1.98 (1.96%)

Notes.
SD, standard deviation; LoA, limit of agreement.

Concurrent validity and agreement

Both instruments showed an excellent correlation for shoulder flexion and abduction at 45° and 90° (r's range = 0.997–0.998) (Table 2). Bland-Altman plots are displayed in Fig. 2. Both HHDs provided almost perfect agreement with small mean 'bias' (ranging from 0.30% to 0.99%) and 'imprecision' (SD range = 2.24% to 2.35%) compared to MicroFet2.

Reliability

Tables 3 and 4 show intra-rater reliability analysis for the DiCI in asymptomatic and symptomatic subjects. Relative reliability analysis showed excellent reliability for the isolated muscle values for both asymptomatic (ICC's range = 0.96 to 0.97) and symptomatic subjects (ICC's range = 0.94 to 0.97). Absolute reliability analysis showed SEMs < 2.18% and MDC < 6.33N in asymptomatic subjects and SEMs < 2.25% and MDC < 3.42N in symptomatic subjects for all movements.

DISCUSSION

The purpose of this study was to investigate concurrent validity and reliability of a new strap-stabilized HHD for the evaluation of shoulder strength. The results of this study showed that the DiCI is a valid and reliable device for the assessment of shoulder flexion and abduction strength.

Consistency between DiCI and MicroFET2 was excellent, showing a very high correlation (r's range = 0.997–0.998) and low mean bias and imprecision (<1%) between devices for

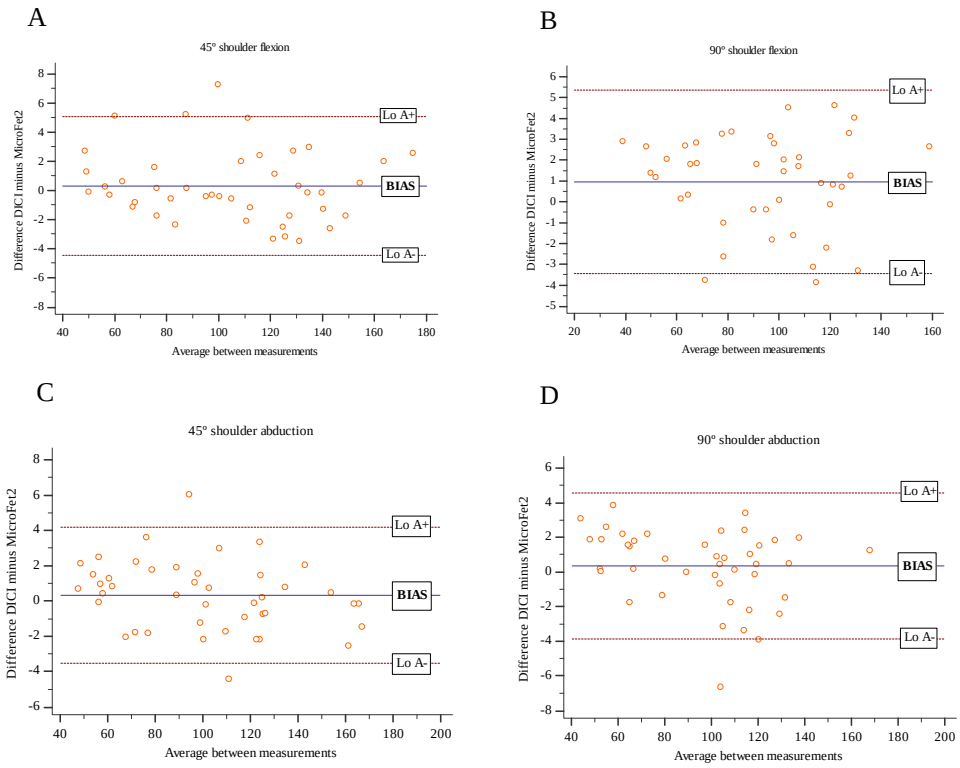

Figure 2 Bland-Altman plots for DiCI and MicroFET2 during isometric strength test in asymptomatic subjects. (A) Shoulder flexion at 45°; (B) shoulder abduction at 90°; (C) shoulder abduction at 45°; (D) shoulder abduction at 90°.

Full-size DOI: 10.7717/peerj.11600/fig-2

Table 3 DiCI reliability of shoulder strength assessment in asymptomatic subjects.[a]

	Difference test–retest mean (SD)	ICC (CI 95%)	SEM (%)	MDC
Flexion				
90°	−3.49 (8.28)	0.96 (0.92–0.97)	1.50 (1.50%)	4.17
45°	−4.12 (10.46)	0.97 (0.96–0.99)	1.62 (1.49%)	4.49
Abduction				
90°	−3.41 (8.94)	0.97 (0.95–0.98)	1.35 (1.36%)	3.76
45°	−3.50 (12.57)	0.96 (0.93–0.98)	2.28 (2.18%)	6.33

Notes.

SD, standard deviation; ICC, intraclass correlation coecient; CI, condence interval; SEM, standard error of measurement; MDC, minimum detectable change.

[a]Strength values in Newtons.

both movements. In terms of agreement, our findings were superior to previous studies that have measured shoulder strength with HHDs, as well as those using methods with *Kolber et al. (2007)*, *Katoh (2015)* and *Romero-Franco (2019)* or without stabilization (*Wikholm & Bohannon, 1991*; *Leggin et al., 1996*; *Vermeulen et al., 2005*). The study by *Vermeulen et al. (2005)*, which did stabilize the HHDs, obtained large variations between devices for the evaluation of shoulder abduction (LoA ranging from 26.30% to 39.10%). Otherwise,

Table 4 DiCI reliability of shoulder strength assessment in symptomatic subjects.[a]

	Test (SD)/Retest (SD)	ICC (CI 95%)	SEM (%)	MDC
Flexion				
45°	54.80 (15.68)/54.59 (18.69)	0.967 (0.92–0.98)	1.23 (2.25%)	3.42
Abduction				
45°	43.36 (7.67)/ 42.28 (8.66)	0.945 (0.90–0.97)	0.87 (2.02%)	2.42

Notes.
SD, standard deviation; ICC, intraclass correlation coecient; CI, condence interval; SEM, standard error of measurement; MDC, minimum detectable change; CCRT, concurrent chemoradiotherapy.
[a]Strength values in Newtons.

the study of *Romero-Franco (2019)* used stabilization between the HHD and the subject, resulting in small differences between devices (LoA ranging from 8.62% to 12.41%). In this way, our results are consistent with the literature and show that HHD stabilization produces better values in terms of bias. Furthermore, the DiCI showed slightly better agreement than other stabilized dynamometers, such as the one studied by Romero-Franco, possibly because force measurement was not the main use in such dynamometer.

The intratester reliability obtained in the strength tests was excellent (ICC ranging from 0.92 to 0.99). Several studies have reported good to excellent ICC results (ICC from 0.76 to 0.99) (*Kolber et al., 2007*; *Schrama et al., 2014*; *Katoh, 2015*; *Romero-Franco, 2019*). Our findings were superior to those of upper limb studies that investigated intratester reliability of HHDs without stabilization (*Schrama et al., 2014*), and slightly superior or similar to those studies that implemented stabilization methods (*Kolber et al., 2007*; *Katoh, 2015*; *Romero-Franco, 2019*). Non-stabilized HHD studies evaluated the same movements as stabilized HHD studies. Such movements were assessed in similar positions but with the examiner using hand pressure on the HHD. On the one hand, in those non-stabilized HHD studies which showed good methodological quality (*Schrama et al., 2014*), ICC values ranged from 0.70 to 0.97 for shoulder flexion, and from 0.86 to 0.94 for shoulder abduction (*Schrama et al., 2014*). On the other hand, in a recent stabilized HHD study, the mean ICC values were 0.97 for shoulder flexion, and 0.97 for shoulder abduction (*Romero-Franco, 2019*). Other stabilized device studies evaluated a greater number of shoulder movements, such as external and internal rotation, shoulder abduction, and shoulder extension, showing mean ICC values > 0.90 (*Kolber et al., 2007*; *Katoh, 2015*; *Romero-Franco, 2019*). Thus, according to relative reliability analysis, both non-stabilized and stabilized HHDs are sufficiently reliable. However, for an evaluative measurement, it is also important to consider absolute reliability analysis to avoid being misled in the interpretation of ICCs (*Vermeulen et al., 2005*).

The absolute reliability analysis of the outcome measures estimates the accuracy of scores on repeated testing in individual subjects (*Walker et al., 2018*). In this way, absolute reliability analysis for DiCI measurements showed SEM values lower than 2.18% and MDC values lower than 6.28% for al movements. In comparison with previous studies, our findings proved to be better than those all which tested shoulder strength with an HHD as a measurement tool, with *Kolber et al. (2007)*, *Katoh (2015)* and *Romero-Franco (2019)* and without *Schrama et al. (2014)* stabilization. In non-stabilized HHD studies, SEM variations

ranged from 8.36% to 23.02% (*Leggin et al., 1996*; *Vermeulen et al., 2005*; *Grooten & Äng, 2010*; *Clarke et al., 2011*; *Hirano & Katoh, 2015*; *Fieseler et al., 2015*). Otherwise, stabilized HHD studies showed SEM and MDC variations in a range between 4.08% and 9.40% (*Kolber et al., 2007*; *Katoh, 2015*; *Romero-Franco, 2019*). In addition, shoulder strength evaluation has normally been performed in asymptomatic subjects, without evaluating whether measurements in patients with movement restriction and lower force values might negatively impact on the reliability of stabilized HHDs. In this regard, our findings showed SEM and MDC values lower than 2.25% and 6.24% respectively for symptomatic subjects, this study being to our knowledge, the first to report absolute reliability results of the stabilized HHD method and showing that it could be a reliable method for shoulder strength measurement in symptomatic subjects. While previous authors have suggested that the intra-rater reliability of HHD measurement may be different in patients as compared with healthy subjects (*Schrama et al., 2014*), our findings for the stabilized HHD method indicate that the reliability of this method is excellent regardless of the subject's condition.

This study provides valuable information on the validity and reliability of the DiCI despite being subject to several limitations. Firstly, measurements were made only in shoulder flexion and abduction at 45° and 90°; this may limit the ability to extrapolate the results to other movements (e.g., shoulder rotation). Secondly, the stabilization method could hinder the use of the DiCI as an HHD as such and could require more time to evaluate strength. Thus, future research should explore other stabilization systems which would facilitate and minimize the time needed to evaluate (e.g., attachment to the examiner's body). Thirdly, only intratester reliability analysis was conducted. Stabilization was proposed to eliminate the error derived from examiner's strength. Thus, considering that the examiner's strength would not affect the evaluation, it seemed appropriate to conduct the intratester analysis only in order to simplify the evaluation procedure.

CONCLUSIONS

The DiCI has been shown to be valid and reliable to assess shoulder abduction and flexion strength at 45° and 90° in symptomatic and asymptomatic subjects. Compared to other HHDs, its use provides clinicians with a valid and reliable device to identify strength deficits, monitor patient recovery, or evaluate the effectiveness of a given intervention. In addition, the DiCI is the first belt-stabilized pull-HDD proven reliable in symptomatic subjects for upper limb strength assessment.

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ADDITIONAL INFORMATION AND DECLARATIONS

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The authors received no funding for this work.

Competing Interests

The authors declare there are no competing interests.

Author Contributions

- Javier González-Rosalén conceived and designed the experiments, performed the experiments, prepared figures and/or tables, and approved the final draft.
- Alba Cuerda-Del Pino performed the experiments, analyzed the data, authored or reviewed drafts of the paper, and approved the final draft.
- Mariana Sánchez-Barbadora analyzed the data, authored or reviewed drafts of the paper, and approved the final draft.
- Rodrigo Martín-San Agustín conceived and designed the experiments, prepared figures and/or tables, and approved the final draft.

Human Ethics

The following information was supplied relating to ethical approvals (i.e., approving body and any reference numbers):

The study was approved by the research ethics committee of the University of Valencia (H1533739889520).

Data Availability

The following information was supplied regarding data availability:

The raw measurements and the codebook are available in the Supplemental Files.

Supplemental Information

Supplemental information for this article can be found online at http://dx.doi.org/10.7717/peerj.11600#supplemental-information.

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ARTÍCULO II

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Intra- and Inter-Rater Reliability of Strength Measurements Using a Pull Hand-Held Dynamometer Fixed to the Examiner's Body and Comparison with Push Dynamometry

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Abstract: Hand held dynamometers (HHDs) are the most used method to measure strength in clinical sitting. There are two methods to realize the assessment: pull and push. The purpose of the present study was to evaluate the intra- and inter-rater reliability of a new measurement modality for pull HHD and to compare the inter-rater reliability and agreement of the measurements. Forty healthy subjects were evaluated by two assessors with different body composition and manual strength. Fifteen isometric tests were performed in two sessions with a one-week interval between them. Reliability was examined using the intra-class correlation (ICC) and the standard error of measurement (SEM). Agreement between raters was examined using paired *t*-tests. Intra- and inter-rater reliability for the tests performed with the pull HHD showed excellent values, with ICCs ranging from 0.991 to 0.998. For tests with values higher than 200 N, push HHD showed greater differences between raters than pull HHD. Pull HHD attached to the examiner's body is a method with excellent reliability to measure isometric strength and showed better agreement between examiners, especially for those tests that showed high levels of strength. Pull HHD is a new alternative to perform isometric tests with less rater dependence.

Keywords: hand-held dynamometer; reliability; pull; push; lower limb; upper limb; strength

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1. Introduction

Quantifying the magnitude of strength is useful for rehabilitation programs, providing helpful information on setting target values, for setting up appropriate exercise loads, and the effectiveness and progress of treatment [1]. The evaluation of strength is one of the usual practices by health professionals to assess healthy individuals [2–4] and in the management patients with different lower limb or upper limb pathologies [5], such as knee osteoarthritis [6], rotator cuff injuries [7], and neurogenic thoracic outlet syndrome [8]. Among the tools to measure strength in clinical sitting, the most used is hand held dynamometers (HHDs) [9], since it has advantages such as portability, cost, and ease of use compared to other more expensive and less versatile methods (i.e., isokinetic dynamometer) [10]. In general, HHDs can be classified into two types, push or pull [1,11–13].

Push HDD consists of the patient having to push against the HHD, which is usually stabilized by the examiner's hand and has been shown to be a reliable method [10,14]. This push mode has the disadvantage that examiner's sex and strength influence the strength values (the reliability increases when the rater is stronger than the subject) [14]. Pull HHD consists of the patient pulling the HHD, which is generally attached to a rigid structure such as espalier, stretcher, or glass suction cup and showing to be also a reliable method [12,15–18].

Therefore, since this method requires a certain infrastructure and make it difficult to carry out certain movements, push HHDs is the type commonly used by clinicians.

To solve the requirement to a structure (e.g., wall bars or stretcher), we propose in this study a new measurement modality for pull HHD (fixing it to the examiner's body). Our hypothesis is that by means of this fixation, the strength of the subject can be counteracted efficiently to have reliable strength values. If this is confirmed, we consider that it may be a more clinically feasible method for routine patient assessment than other pull HHD methods because it does not need infrastructures. Therefore, the main objective of this study was to evaluate the intra- and inter-rater reliability of this new measurement modality for pull HHD. Since previous studies have shown the influence of examiner's strength on measurements with HHD, we used for our purpose two examiners and several muscles with different levels of strength. Furthermore, a secondary objective was to compare the inter-rater reliability and agreement of the measurements of this pull HHD method versus the push HHD method against the hand, as a common method of isometric strength measurement.

2. Materials and Methods

This cross-sectional study enrolled 40 healthy volunteer subjects who were recruited through advertising in Blasco Ibañez Campus of the University of Valencia (Table 1 shows the participants' characteristics). The specific inclusion criteria were: (1) participants' age between 18 and 40 years; (2) not having undergone a surgical operation on the lower or upper limb in the last two years; and (3) not having suffered pain episodes in the lower or upper limb two months before data collection. After a detailed explanation of the study procedures, the participants signed informed consent. The experimental protocol was approved by the Ethics Committee of the University of Valencia (Spain) (H1533739889520). Data collection was carried out in the clinical research laboratory of the Department of Physiotherapy (University of Valencia).

Table 1. Characteristics of the participants (n = 40).

	Mean (SD)	Range
Age (years)	27.3 (5.1)	19–39
Body mass (kg)	66.2 (14.2)	47–94
Stature (cm)	170.7 (8.7)	152–192
BMI (kg/m^2)	22.5 (3.4)	17.1–30.1
Gender	Males (n = 20)	Females (n = 20)

2.1. Procedures

Two sports and health professionals (a female and a male) were chosen to carry out the isometric tests, both with 1 year of clinical experience and with a master's degree. Both raters, with different body composition (body mass: 55.4 kg and 91.3 kg and stature: 166 cm and 180 cm, respectively) were chosen to reflect different profiles of clinicians working both clinical and research settings. As previous authors [13], the raters completed a test of one maximum repetition of seated bench press as an indicator of general upper-extremity strength (47 kg for female tester and 81 kg for male tester). Raters received a 1-h training session on how to perform the measurements with both the pull HHD and the push HHD. Following the training, they performed testing procedures with 3 volunteers, supervised in turn by a health professional with extensive HHD experience. Both examiners were blinded to the strength values, with a third researcher responsible for viewing the strength values and recording them.

The pull HHD selected for the study was DiCI (Ionclinics S.L, L'Alcudia, Spain), which registers the traction strength through two hooks in series [19]. For the DiCI measurement, one end was attached with a strap to the subject's ankle or wrist and the other end, with a belt, to the examiner's body (Appendix A). On the other hand, the push HHD used was MicroFET2 (Hoggan Health Technologies Inc., Salt Lake City, UT, USA), widely used in the literature [20,21].

Isometric tests were performed on the dominant leg or arm in two sessions with a one-week interval between them. The two sessions began evaluating the strength using the pull HHD by tester 1 (male) and, thus, evaluating the intra-tester reliability (both intrasession and intersession). Subsequently, the isometric strength of the participants was again measured either by rater 1 or rater 2, randomly, with the pull HHD the first session and with the push HHD the second session in order to examine the inter-rater reliability of each HHD (Figure 1).

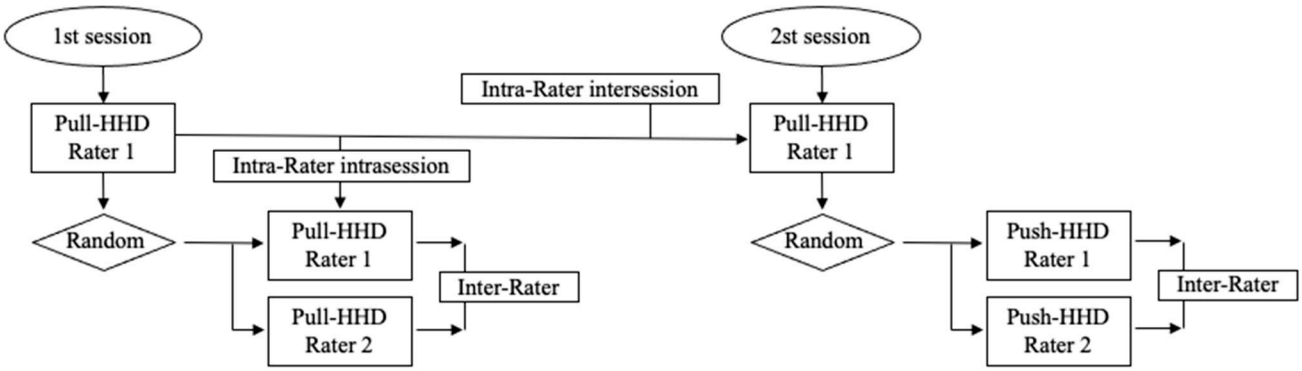

Figure 1. Flow chart represents a process of the study.

Before performing the isometric tests, the anthropometric characteristics of the participants were measured. A warm-up was performed on a bicycle with low resistance and at comfortable speed (80 revolutions per minute) for 10 min and three submaximal isometric contractions for each position. In addition, these submaximal contractions were also used to familiarize the participants with correct execution of the tests.

All tests were performed on a stretcher. The lower limb tests were performed both in the supine position for hip abduction (Hip-ABD), hip adduction (Hip-ADD), ankle flexion (Ank-F), and ankle extension (Ank-E) tests; in the prone position for hip extension (Hip-E), hip rotation external (Hip-ER), and internal (H-IR); and in the sitting position for hip flexion test (Hip-F). The upper limb tests were performed in supine for elbow flexion (Elb-F) and extension (Elb-E), for shoulder flexion (Sho-F), extension (Sho-E), and abduction (Sho-A), and for shoulder internal rotation (Sho-IR) and external (Sho-ER). These isometric tests (Figures A1 and A2), both for lower and upper limb, were selected because they showed small measurement variation in previous studies [13,22,23]. Test order were randomized for each participant to avoid systematic bias related to this. Two 5 s MVICs were performed per movement with 60 s of rest between measurements. A rest of 10 min was applied between rater measurements. The participants were instructed to make the maximum effort and received oral motivations to maintain the strength performed.

2.2. Statistical Analysis

Participant characteristics and strength values (Newtons) are presented as mean ± standard deviation (SD) or percentages, as appropriate. The mean between repetitions was used for analyses. Custom written scripts computed with MATLAB (version R2019b; The Mathworks, Natick, MA, USA) was used to perform all statistical analyses by a researcher blinded for measurements.

First, for the analysis of the reliability, the values examined were: (1) the relative reliability using the intra-class correlation (ICC) and (2) the absolute reliability by calculating the standard error of measurement (SEM). The reliability was classified as excellent (ICC > 0.90), good (ICC = 0.76–0.90), moderate (ICC = 0.51–0.75), and poor (ICC < 0.50) [24,25]. SEM was calculated as SEM = $SD\sqrt{(1 - ICC)}$.

Second, for the analysis of the agreement between the strength measurements (rater 1 and rater 2) and to assess systematic between-rater bias, that is, if values obtained by

one rater systematically differed from that of the other rater, paired *t*-tests were used [26]. Furthermore, the differences between raters were calculated for each method and they were compared using paired *t*-test, with a level of significance $p < 0.05$. Additionally, to illustrate the differences between HHDs as a function of the strength obtained, the Bland Altmann plots were performed in those tests with higher strength values.

Sample size was calculated using the formula for reliability studies based on confidence intervals (CIs) described by [27]. With the number of instruments (k) equal to 2, the CI around r (the reliability coefficient) of 0.05, and an estimated r of 0.95, the sample size (n) was calculated to be 25 participants. However, ultimately, we included 15 more participants in the final sample in order to increase the study power.

3. Results

3.1. Intra-Rater Reliability

Table 2 shows the intra-rater reliability for the tests performed with the pull HHD, both intra-session and inter-sessions. The intra-session reliability showed excellent values, with ICCs ranging from 0.996 to 0.998. Furthermore, the SEM values were less than 1%. The inter-session reliability obtained similar values, with ICC higher than 0.995 and SEMs lower than 1%.

Table 2. Intra-rater reliability for the pull HHD method by movement and session.

			Intra-Session			Inter-Session	
Isometric Test		**Test (SD)**	**ICC (95% CI)**	**SEM (%SEM)**	**Retest (SD)**	**ICC (95% CI)**	**SEM (%SEM)**
Hip	Flexion	350.67 (125.19)	0.996 (0.993 to 0.999)	0.12 (0.03%)	350.49 (126.09)	0.998 (0.996 to 0.999)	0.14 (0.04%)
	Extension	210.32 (70.68)	0.997 (0.993 to 0.999)	0.09 (0.04%)	210.34 (71.5)	0.998 (0.996 to 0.999)	0.11 (0.05%)
	Abduction	129.72 (26.93)	0.998 (0.995 to 0.999)	0.05 (0.04%)	130.77 (27.61)	0.995 (0.992 to 0.998)	0.15 (0.12%)
	Adduction	144.88 (45.38)	0.998 (0.995 to 0.999)	0.07 (0.05%)	145.19 (45.77)	0.998 (0.995 to 0.999)	0.09 (0.06%)
	IN rotation	115.15 (33.87)	0.996 (0.992 to 0.999)	0.08 (0.07%)	115.11 (34.22)	0.996 (0.992 to 0.998)	0.20 (0.17%)
	EX rotation	129.34 (39.83)	0.998 (0.995 to 0.999)	0.06 (0.05%)	129.93 (39.32)	0.996 (0.993 to 0.998)	0.20 (0.16%)
Ankle	Flexion	305.85 (131.1)	0.998 (0.996 to 0.999)	0.10 (0.03%)	306.06 (131.81)	0.996 (0.993 to 0.999)	0.26 (0.08%)
	Extension	255.11 (116.06)	0.998 (0.996 to 0.999)	0.11 (0.04%)	256.04 (115.76)	0.998 (0.996 to 0.999)	0.10 (0.04%)
Shoulder	Flexion	212.91 (87.21)	0.997 (0.995 to 0.999)	0.13 (0.06%)	212.12 (87.02)	0.998 (0.995 to 0.999)	0.16 (0.07%)
	Extension	297.3 (141.38)	0.998 (0.996 to 0.999)	0.07 (0.02%)	298.41 (142.39)	0.997 (0.993 to 0.999)	0.14 (0.05%)
	Abduction	106.27 (40.21)	0.997 (0.994 to 0.999)	0.08 (0.07%)	106.52 (40.2)	0.998 (0.995 to 0.999)	0.08 (0.08%)
	IN rotation	141.32 (50.92)	0.998 (0.995 to 0.999)	0.09 (0.06%)	141.59 (51.39)	0.998 (0.995 to 0.999)	0.08 (0.06%)
	EX rotation	138.73 (45.26)	0.998 (0.995 to 0.999)	0.07 (0.05%)	138.99 (45.51)	0.996 (0.994 to 0.999)	0.14 (0.10%)
Elbow	Flexion	219.72 (113.09)	0.998 (0.996 to 0.999)	0.10 (0.04%)	219.13 (112.26)	0.998 (0.996 to 0.999)	0.17 (0.08%)
	Extension	161.26 (68.54)	0.998 (0.996 to 0.999)	0.08 (0.05%)	161.24 (68.3)	0.998 (0.995 to 0.999)	0.11 (0.07%)

SD = standard deviation; ICC = intra-class correlation; CI = confidence interval; SEM = standard error of measurement; IN = Internal; EX = External.

3.2. Inter-Rater Reliability

Table 3 shows the inter-rater reliability and agreement for the tests performed with the pull HHD. All tests showed excellent reliability (ICCs > 0.991), with SEMs lower than 1%. The agreement between rater showed differences between the measurements of rater 1 and rater 2 ranging from −0.69% to −3.78%, always in favor of rater 1.

Table 3. Inter-rater reliability and agreement for pull HHD method by movement.

Isometric Test		Rater 1 (Male) Mean (SD)	Rater 2 (Female) Mean (SD)	ICC (95% CI)	SEM (%SEM)	Rater Differences (Rater 2 Minus Rater 1) Mean (%)	SD Difference Mean (%)
Hip	Flexion	351.92 (125.58)	339.22 (118.2)	0.992 (0.985 to 0.996)	1.95 (0.58%)	−12.70 (−3.61%)	21.82 (6.2%)
	Extension	210.28 (70.26)	208.84 (73.85)	0.991 (0.984 to 0.996)	1.26 (0.60%)	−1.44 (−0.69%)	13.24 (6.3%)
	Abduction	130.23 (26.94)	127.76 (26.16)	0.995 (0.991 to 0.998)	0.26 (0.20%)	−2.47 (−1.9%)	3.61 (2.77%)
	Adduction	145.33 (45.71)	142.34 (43.1)	0.998 (0.995 to 0.999)	0.19 (0.14%)	−2.99 (−2.06%)	4.36 (3%)
	IN rotation	115.68 (34.1)	113.19 (33.29)	0.995 (0.991 to 0.997)	0.33 (0.30%)	−2.49 (−2.15%)	4.73 (4.09%)
	EX rotation	129.62 (39.51)	127.53 (39.15)	0.998 (0.996 to 0.999)	1.13 (0.89%)	−2.08 (−1.61%)	3.57 (2.75%)
Ankle	Flexion	307.38 (130.95)	295.75 (123.9)	0.995 (0.991 to 0.998)	1.22 (0.41%)	−11.63 (−3.78%)	17.21 (5.6%)
	Extension	256.23 (116.67)	249.11 (113.42)	0.997 (0.995 to 0.999)	0.66 (0.26%)	−7.11 (−2.78%)	11.97 (4.67%)
Shoulder	Flexion	213.75 (87.17)	206.96 (83.27)	0.996 (0.993 to 0.998)	0.65 (0.31%)	−6.79 (−3.18%)	10.25 (4.79%)
	Extension	298.43 (141.48)	289.95 (132.62)	0.996 (0.993 to 0.998)	1.09 (0.37%)	−8.48 (−2.84%)	17.18 (5.76%)
	Abduction	106.83 (40.49)	104.96 (39.64)	0.999 (0.998 to 1)	0.07 (0.07%)	−1.87 (−1.75%)	2.31 (2.16%)
	IN rotation	139.37 (45.6)	139.03 (50.25)	0.999 (0.998 to 1)	0.09 (0.06%)	−2.79 (−1.97%)	2.86 (2.01%)
	EX rotation	141.82 (50.14)	136.53 (44.59)	0.997 (0.995 to 0.999)	0.25 (0.19%)	−2.84 (−2.04%)	4.63 (3.32%)
Elbow	Flexion	219.91 (112.98)	213.06 (106.79)	0.998 (0.996 to 0.999)	0.46 (0.22%)	−6.85 (−3.12%)	10.36 (4.71%)
	Extension	161.62 (68.68)	158.61 (67.36)	0.999 (0.998 to 1)	0.13 (0.08%)	−3.02 (−1.87%)	4 (2.47%)

SD = standard deviation; ICC = intra-class correlation; CI = confidence interval; SEM = standard error of measurement; IN = Internal; EX = External.

Figure 2 illustrates differences between raters for the measurements of each participant, in the lower limb (Figure 2A) and the upper limb (Figure 2B). As can be seen, for some movements (e.g., hip abduction/adduction or hip rotations) both the pull and the push HHD methods showed differences lower than 20 N (rater differences ranged between 0.20% to 0.89% for pull HHD (Table 3) and between 0.26% to 1.59% for push HHD (Table 4)). On the other hand, for movements such as Hip-F, Ank-F, or Sho-E, both methods show greater differences between raters, but these are greater for the push HHD than for the pull HHD method; the differences between raters are −3.61%, −3.78%, and −2.84% for the pull HHD (Table 3) and −9.68%, −12.91%, and −9.71% for the push HHD (Table 4).

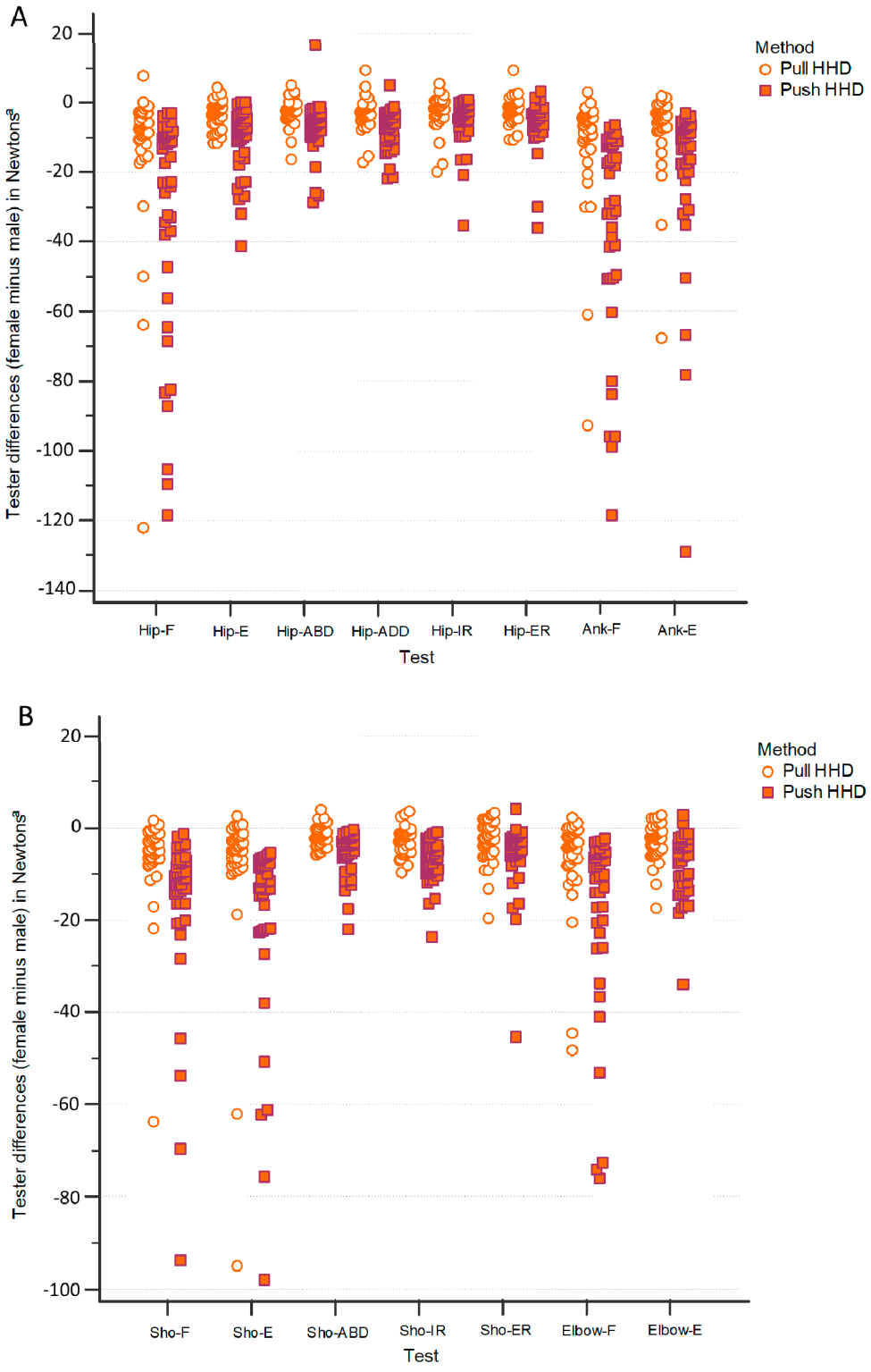

Figure 2. Differences between raters in the lower limb (**A**) and in the upper limb (**B**) for the strength measurements in each participant by test and method.

Table 4. Inter-rater reliability and agreement for the push HHD method by movement.

Isometric Test		Rater 1 (Male) Mean (SD)	Rater 2 (Female) Mean (SD)	ICC (95% CI)	SEM (%SEM)	Rater Differences (Rater 2 Minus Rater 1) Mean (%)	SD Difference Mean (%)
Hip	Flexion	337.38 (114.98)	304.74 (110.26)	0.979 (0.96 to 0.989)	4.72 (1.55%)	−32.64 (−9.68%)	32.57 (9.65%)
	Extension	203.01 (67.13)	195.45 (74.97)	0.966 (0.935 to 0.982)	4.77 (2.44%)	−7.56 (−3.72%)	25.87 (12.74%)
	Abduction	128.24 (25.14)	120.92 (24.19)	0.976 (0.955 to 0.987)	1.17 (0.97%)	−7.32 (−5.71%)	7.54 (5.88%)
	Adduction	142.61 (43.17)	134.92 (41.84)	0.996 (0.992 to 0.998)	0.35 (0.26%)	−7.69 (−5.39%)	5.55 (3.89%)
	IN rotation	115.80 (33.81)	110.55 (32.75)	0.989 (0.980 to 0.994)	0.72 (0.65%)	−5.24 (−4.53%)	6.84 (5.91%)
	EX rotation	128.79 (38.69)	122.69 (36.54)	0.991 (0.983 to 0.995)	1.95 (1.59%)	−6.10 (−4.74%)	7.15 (5.55%)
Ankle	Flexion	289.92 (114.83)	252.50 (103.33)	0.978 (0.943 to 0.984)	6.48 (2.57%)	−37.43 (−12.91%)	37.40 (12.90%)
	Extension	248.60 (106.19)	228.64 (103.26)	0.987 (0.975 to 0.993)	2.75 (1.20%)	−19.97 (−8.03%)	24.08 (9.69%)
Shoulder	Flexion	201.07 (79.36)	183.95 (70.6)	0.985 (0.971 to 0.992)	2.25 (1.22%)	−17.11 (−8.51%)	18.37 (9.14%)
	Extension	278.45 (124.56)	251.41 (107.06)	0.964 (0.933 to 0.981)	8.18 (3.25%)	−27.04 (−9.71%)	43.09 (15.47%)
	Abduction	103.24 (37.35)	97.82 (35.53)	0.996 (0.992 to 0.998)	0.30 (0.30%)	−5.42 (−5.25%)	4.72 (4.57%)
	IN rotation	139.51 (48.38)	132.03 (47.82)	0.991 (0.983 to 0.995)	0.43 (0.33%)	−7.48 (−5.36%)	4.49 (3.22%)
	EX rotation	136.70 (43.78)	130.50 (39.61)	0.998 (0.996 to 0.999)	0.35 (0.27%)	−6.20 (−4.53%)	7.92 (5.79%)
Elbow	Flexion	207.87 (99.62)	189.79 (89.26)	0.989 (0.979 to 0.994)	2.09 (1.10%)	−18.09 (−8.70%)	19.91 (9.58%)
	Extension	156.50 (65.6)	148.00 (64.08)	0.997 (0.995 to 0.998)	0.38 (0.26%)	−8.49 (−5.43%)	6.93 (4.43%)

SD = standard deviation; ICC = intra-class correlation; CI = confidence interval; SEM = standard error of measurement; IN = Internal; EX = External.

The differences by method as a function of the strength obtained in these three tests are illustrated in Figure 3 by means of the Bland Altman plots. Bland Altman plots show how from strength values greater than 200 N, the differences between raters for the push HHD increase progressively, while the differences in the pull HHD remain stable.

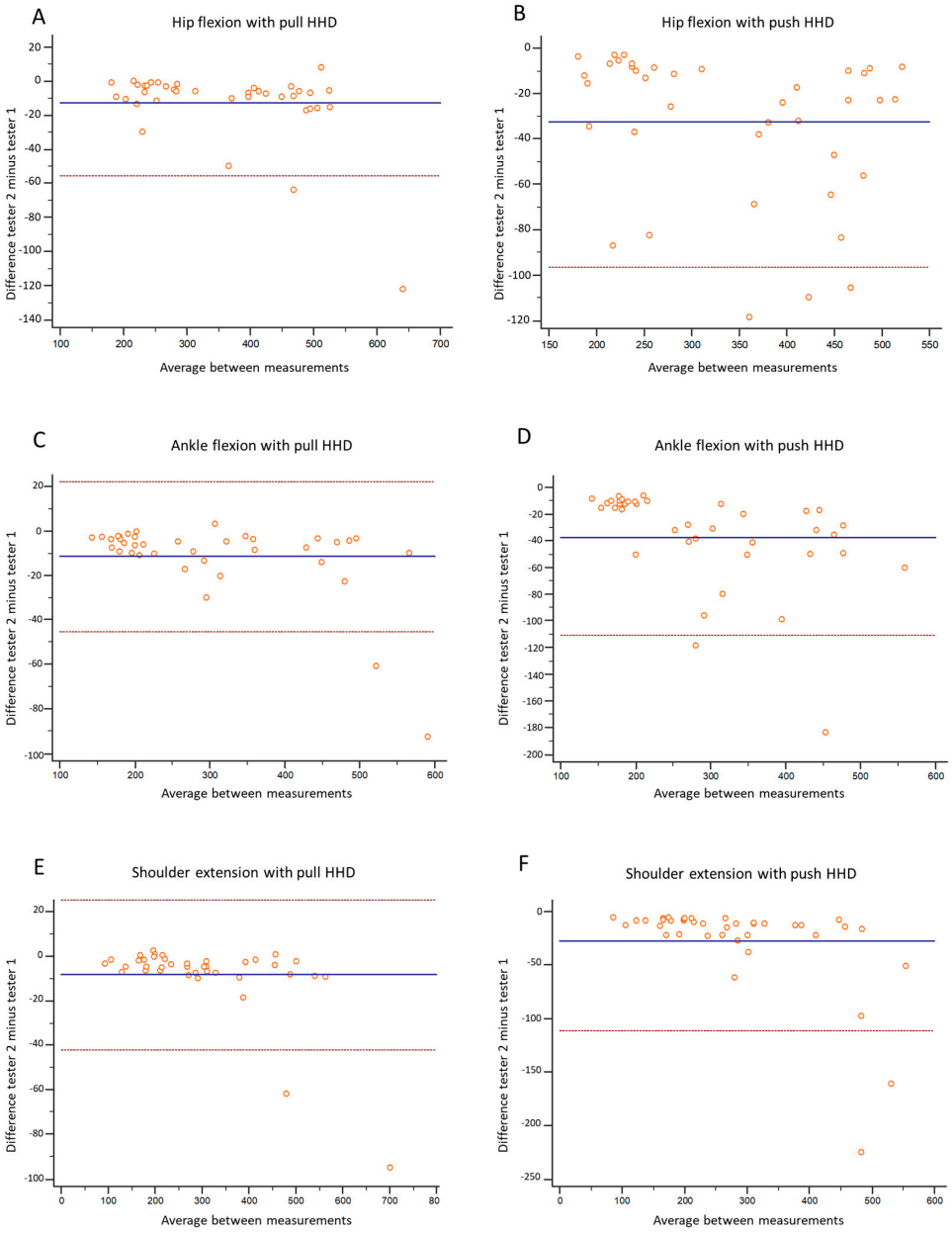

Figure 3. Bland Altman plots of the rater differences for pull HHD (**A**,**C**,**E**) and push HHD (**B**,**D**,**F**) methods as a function of total strength obtained in hip flexion (**A**,**B**), angle flexion (**C**,**D**), and shoulder extension (**E**,**F**).

4. Discussion

Our results support our initial hypothesis that stabilizing a pull HHD to the examiner's body has excellent reliability achieved for isometric strength measurements performed by examiners with different manual strength and in tests with different strength values. In addition, this new method presents a better agreement between examiners than push HHD against the hand, especially for tests with strength values greater than 200 N.

To our knowledge, this study is the first to examine the reliability of a pull HHD attached to the examiner's body. Intra-reliability for this method proved to be excellent (ICCs > 0.998). Other studies with stabilized pull HHDs (these to a fixed external element) have also obtained high ICCs for intra-rater reliability, both for hip and ankle tests (ICCs ranged from 0.88 to 0.98) [12] and shoulder tests (ICCs ranged from 0.94 to 0.98) [16,17]. Otherwise, compared with other studies where they have used pull HHD attached to

structures, our method showed ICCs for inter-rater reliability (ICCs > 0.991) similar or slightly superior to those studies (ICCs ranging from 0.69 to 0.99 for hip tests, from 0.76 to 0.99 for ankle tests, and from 0.86 to 98 for shoulder tests) [12,15,17,28]. Thus, the reliability of attaching a pull HHD to the examiner's body would not be inferior to attaching it to a fixed external element.

The agreement between the examiners' measurements proved to be different between methods, especially in those tests with strength values greater than 200 N. As previous authors have described, in those tests with values greater than 200 N, the measurements of HHD without fixation compared to with fixation tend to underestimate the strength values [13,29]. Our results provide the novelty that fixing the HHD to the examiner's body is sufficient to reduce such underestimation. For example, in tests such as Hip-F or Ank-F (with values close to or greater than 300 N), the differences between raters for the push HHD were 9.68% and 12.91%, respectively, compared to 3.61% and 3.78% for the pull HHD. In the upper limb this is similar, where the Sho-E, with values close to 300 N, showed differences between testers of 9.71% for push HHD versus 2.84% for pull HDD. The differences for push HHD between raters are similar to studies that have also used examiners with different strengths. For example, Kelln et al., 2008 found 8.87% differences for Ank-F [30].

This study proposes a new method to perform isometric tests, stabilizing an HHD pull in the examiner's body. This method has shown excellent inter- and intra-rater reliability, and compared to other methods, its use provides clinical advantages for sports and health professionals. First, compared to other methods that have tried to solve the problem of examiner interaction (e.g., fixing the HHD to espalier, metal bar, or glass suction cup) [12,15,17,28,31,32], pull HHD method of this study presents a similar reliability to such methods but without subtracting clinical application as it does not need external fixation or is limited to specific movements. Second, pull HHD reduces the interaction of the examiner's strength compared to the use of push HHD against the hand. Since push HHD is a common method of strength measurement among sports and health professionals due to its easy use, but it presents the bias of the examiner's interaction, pull HHD fixed to the examiner's body can be an alternative of easy use and less bias. Likewise, other types of clinical test has been used to assess the muscle performance, but with weak positive correlation against HHD [33].

This study had several strengths. First, we performed multiple tests of both lower limb and upper limb movements, eight and seven, respectively. To the best of our knowledge, this is the first study to examine the reliability of fifteen isometric tests, so we proposed a broad measurement protocol with HHD in the same study. Second, we avoided an information bias, since the raters were blinded from the strength values as there was a third researcher who was in charge of reading and recording them. In turn, a fourth researcher in charge of the statistical analysis was blinded as to which HHD corresponded to the different strength records.

The main limitation was that the measurements were made on a healthy population, limiting their generalization to other populations. Although it has been shown that the reliability of HHDs is lower in healthy population than in patients (due to greater strength and less variability), future studies should examine our protocol in clinical populations. Likewise, the inter-rater reliability was carried out by two raters, a procedure that according to the literature is sufficient for validation, but that the involvement of three or more raters might have provided even more reliable information. Future studies should address this limitation by considering, at least, three raters. Even so, we consider that this first study is essential to provide normative values in healthy people with which to compare.

5. Conclusions

This study examines the intra-and inter-rater reliability of a new proposal to measure isometric strength, a pull HHD attached to the examiner's body. This method showed excellent reliability and acceptable agreement between the examiners' measurements, who

had a different body and strength profile. Furthermore, compared to the traditional method of strength measurement with HHD, pushing against the examiner's hand, pull HHD showed better agreement between examiners, especially for those tests that showed high levels of strength. Thus, this new use of pull HHD may represent a new alternative for professionals who want to perform isometric tests with less influence of their strength on the values.

Author Contributions: J.C.B.-M., F.M.-M., and R.M.-S.A. designed the study and conducted the literature search. J.G.-R., A.C.-D.P., and R.M.-S.A. were responsible for data acquisition. A.C., F.M.-M., and R.M.-S.A. were involved in data analysis and interpretation. J.C.B.-M., F.M.-M., and R.M.-S.A. were involved in writing the manuscript. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Institutional Review Board of UNIVERSITY OF VALENCIA (SPAIN) (protocol code H1533739889520, 7 February 2020).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The datasets generated during and/or analyzed during the current study are available from the corresponding authors on reasonable request.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

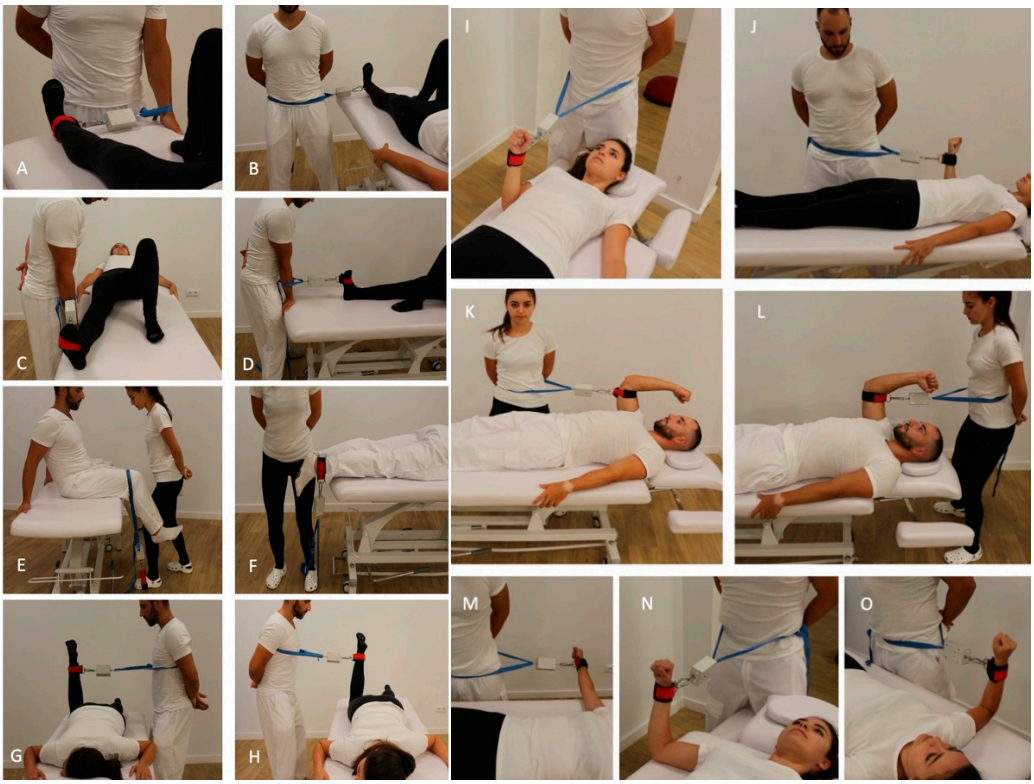

Figure A1. Isometric strength tests using pull HHD for: hip abduction (**A**), hip adduction (**B**), ankle flexion (**C**), ankle extension (**D**), hip flexion (**E**), hip extension (**F**), hip rotation internal (**G**), hip rotation external (**H**), elbow extension (**I**), elbow flexion (**J**), shoulder flexion (**K**), shoulder extension (**L**), shoulder abduction (**M**), shoulder internal rotation (**N**), and shoulder internal external (**O**).

Figure A2. Isometric strength tests using push HHD for: hip abduction (**A**), hip adduction (**B**), ankle flexion (**C**), ankle extension (**D**), hip flexion (**E**), hip extension (**F**), hip rotation internal (**G**), hip rotation external (**H**), elbow extension (**I**), elbow flexion (**J**), shoulder flexion (**K**), shoulder extension (**L**), shoulder abduction (**M**), shoulder internal rotation (**N**), and shoulder internal external (**O**).

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ARTÍCULO III

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diagnostics

MDPI

Article

Analysis of Compliance with Time under Tension and Force during Strengthening Exercises with Elastic Bands

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Abstract: Quantifying training variables of a physical exercise modality is essential for an appropriate dosage. In training with elastic bands, time under tension (TUT) and force represent the duration and intensity of this force-training modality. The aims of this study were to evaluate the degree of compliance to TUT prescription for three different scenarios of two exercises and the comparison of the force values obtained versus the estimate values. A total of 29 healthy volunteers were evaluated in a clinical environment under controlled conditions in 3 different scenarios (different velocities or ROMs) of both shoulder abduction and knee extension in 2 sets of 10 repetitions per scenario within a single session. Concentric and isometric phases showed a higher degree of compliance for their TUTs than the eccentric phase TUTs for all scenarios of both exercises, whereas the degree of compliance was higher for the total TUT than for the phases' TUTs. Additionally, the eccentric phase showed a general tendency to develop for longer time periods than prescribed, whilst the fast scenario showed a higher degree of compliance for isometric phase TUTs and total TUTs than the extant two scenarios in both exercises. On the other hand, the force of the elastic bands tends to be overestimated according to the estimates of the manufacturers. These findings, both those related to the degree of compliance with TUTs and the force analysis, can be used by physiotherapists and other exercise professionals as a reference to achieve a good dosage of routine exercises with elastic bands.

Keywords: elastic band; adherence; time under tension; strength training

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1. Introduction

Physical exercise has been widely implemented in different fields, ranging from training to rehabilitation of injuries [1,2]. In multiple pathologies, physical interventions are a primary strategy included in clinical guidelines for the management of the disease, whether in acute, subacute, or chronic musculoskeletal injuries [3–5]. In addition, exercise has been proposed as an adjunctive treatment recommendation in other conditions in which it exerts the function of second-line treatment and improves the course of the pathology [6] as in type 1 diabetes [7–9], cancer survivors [10], fibromyalgia [11–13], or patients undergoing long-term haemodialysis [14–16].

Aerobic endurance exercise and resistance training have been traditionally implemented as training modalities in rehabilitation programs [1,2,17]. Although both can promote substantial benefits when appropriately prescribed, most of the evidence supports the inclusion of resistance training ahead of endurance training in current recommendations and guidelines [6,17,18]. Even though several studies confirm the health benefits of resistance training, physical activity on individuals with pathology should be individually tailored to prevent adverse reactions [1]. Thus, aspects of physical exercise in relation to

prescription such as the type, frequency, intensity, and duration are critical in the implementation of exercise in a clinical environment [1,6]. The management of the aforementioned training variables in a clinical setting is usually developed by physiotherapists for a specific purpose, based on each patient's condition [6,18].

Exercise interventions are usually divided into supervised gym-based programs and home-based training programmes [19]. Gym-based programmes may have an advantage over home-based programmes by controlling the amount and quality of direct training and supervision. However, following a home-based rehabilitation programme promotes the acquisition of a more active role in patients and improves the attachment to physical activity, along with behavioural change techniques [6,18,19].

Among the different methods of applying load in resistance training in home-based programmes, elastic bands have proven to be effective in the rehabilitation of shoulder, neck, knee, and hip pain [20]. Home-based rehabilitation is one of the potential beneficiaries of the implementation of elastic bands in training due to their low price, adaptability to different environments, and simple ability to progress [9,21]. Together with type, frequency, and intensity, time under tension (TUT) is a specific and important training variable in elastic band exercises. Total TUT reflects the time component of a strengthening exercise and refers to the sum of concentric, quasi-isometric, and eccentric contraction phases in a single training set [20,22,23]. Previous research on elastic band rehabilitation programs has proposed three different scenarios related to commonly prescribed home strengthening exercises, which represent either explosive, traditional strength exercises, or strength exercises where the full range of motion (ROM) cannot be obtained [20,23,24]. Despite the fact that the benefits of a training programme depend directly on the degree of compliance with the prescription, the study of prescribed TUTs in different exercises and scenarios has not been previously evaluated. Moreover, knowing the tension (i.e., intensity) that the elastic band performs is also essential for an appropriate dosage. Thus, although manufacturers usually provide tension values according to the percentage of elongation of the elastic band, several authors have shown that these are not usually accurate after a laboratory analysis [25]. Therefore, the first objective of this study was to analyse TUTs during different exercises and scenarios to evaluate the degree of compliance of the subjects for the prescribed scenarios. A second objective was to evaluate the tension obtained during these scenarios and to compare it with the estimated values.

2. Materials and Methods

2.1. Experimental Approach to the Problem

A cross-sectional study design was used to determine TUT and force parameters of elastic band training for shoulder abduction and knee extension. Each exercise was performed in three different scenarios (different velocities or ROMs), in 2 sets of 10 repetitions per scenario. All measurements were made in a single session under similar conditions of temperature (21 °C) and light in the clinical research laboratory of the Department of Physiotherapy (University of Valencia, Valencia, Spain).

2.2. Subjects

A total of 29 healthy volunteers (24 males; mean age: 23.6 ± 2.9 years; body mass: 75.8 ± 11.3 kg; stature: 176.4 ± 6.6 cm; weekly physical activity: 413.4 ± 179.5 min) who were recreationally active (engaging in 1–5 h of moderate physical activity 3–4 days per week) [26] were evaluated; all of them were students from the University of Valencia. All participants practiced recreational sports such as running, swimming, cycling, or general strength training. Subjects with injuries, diseases, or pain preventing proper exercise were excluded. The experimental protocol was approved by the Ethics Committee of the University of Valencia (Spain) (1239215). Once the study procedures were explained to the participants in detail, they signed informed consent and completed the demographic information sheet prior to data collection.

2.3. Procedures

Before measurements, subjects were requested not to participate in any strenuous exercise during the previous 48 h. The evaluation session started with a standard warm-up, which consisted of walking up and down several flights of stairs and performing weight-free shoulder abductions. Shoulder abduction and knee extension with elastic bands were evaluated in three common elastic band training scenarios: (I) 0–90° at high velocity, (II) 0–90° at low velocity, and (III) 0–45° at low velocity [20]. These scenarios have been proposed to represent either (I) explosive, (II) traditional strength exercises, or (III) strength exercises where full ROM cannot be obtained, as it is often stated in patients with severe shoulder impingement [20]. In turn, each scenario has a set time associated with each one of the 3 movement phases (concentric, isometric, eccentric) and a rest time between repetitions as follows: (I) 1/2/1/1 s, (II) 3/2/3/2 s, and (III) 1.5/2/1.5/2 s [20]. The velocity of execution of each scenario was provided to the participants through feedback from a metronome. Furthermore, the participants were verbally guided if they did not follow the beat of the metronome.

The guidelines established for performing shoulder abduction were proposed in previous studies [27] as follows: (I) hip-width distance between the feet, (II) 30° horizontal flexion, (III) palm facing the floor, and (IV) slight elbow flexion. For knee extension, subjects sat on a quadriceps extension machine with a 90° hip flexion and an elastic band perpendicularly anchored to the ankle five cm above the malleoli (Figure 1). The order of the exercises and scenarios was randomised using a randomised number system for both exercises and scenarios.

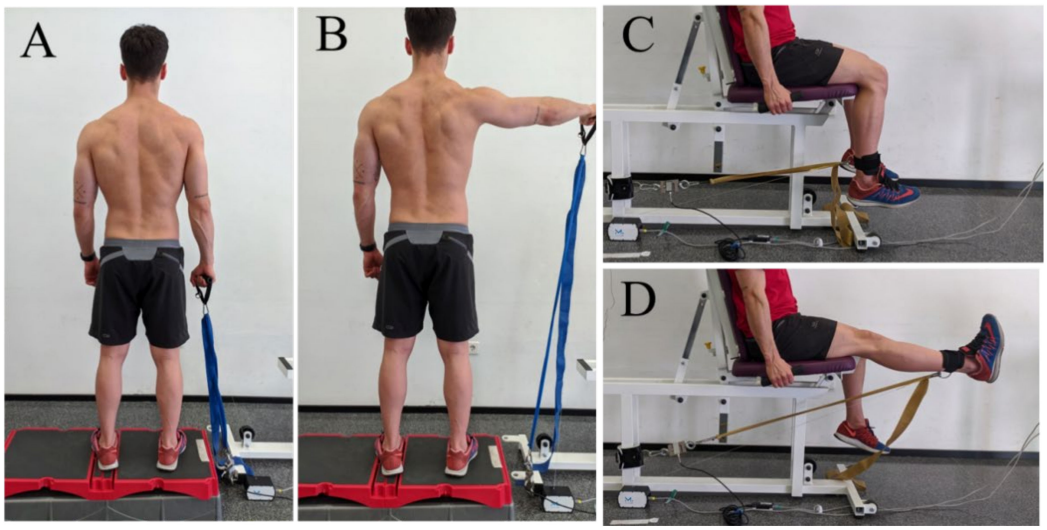

Figure 1. Shoulder abduction setup (**A**,**B**) using a force gauge anchored to the traction end of the elastic band and a linear encoder to assess velocity and elongation. Starting point in a step to avoid the height of the force gauge. Knee extension setup (**C**,**D**) using the same procedure, starting at 90° of hip and knee flexion, reaching maximum knee extension, and ending in the starting point.

The elastic bands used were TheraBand CLX (The Hygenic Corporation, Akron, OH, USA): blue for abduction and golden for extension with a length of 40 cm (i.e., 2 loops), which are commonly used in rehabilitation studies [28–30]. The traction end of the elastic band was anchored to either a handle for abduction or an ankle brace for extension. The fixed end of the elastic band was anchored to a force gauge (MuscleLab 4020e, Ergotest Technology AS, Porsgrunn, Norway) (Figure 1). Since the shoulder abduction exercise is generally performed by stepping on the elastic band [20,24,27], the subjects were placed in a step to avoid the height of the force gauge. The movement velocity and elongation length of the elastic band were evaluated using a linear encoder (MuscleLab 4020e, Ergotest Technology AS, Porsgrunn, Norway) anchored to the handle or ankle (Figure 1). The

participants had two familiarisation attempts per scenario. With a slight tension of the elastic band in the starting position (i.e., the minimum to avoid wrinkles in the elastic band), the subjects had to perform 2 sets of 10 repetitions per exercise and scenario, with 2 min of rest between sets.

The linear encoder and force gauge information was recorded by the Data Synchronisation Unit (DSU) ML6000 (MuscleLab 4020e, Ergotest Technology AS, Porsgrunn, Norway) [31], which is the unit where the MuscleLab 4020e sensors are connected and integrated. Movement phases and TUTs and force parameters were calculated using custom-written scripts computed with MATLAB (version R2019b; The Mathworks, Natick, MA, USA). The phase of the movement for each repetition was determined from the velocity: positive for the concentric phase, around 0 m/s for the isometric phase, and negative velocity for the eccentric phase (Figure 2).

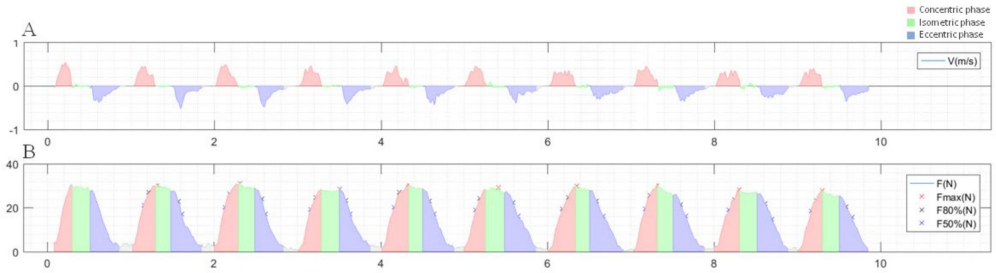

Figure 2. Graph of the information processed by MATLAB for a series of 90° shoulder slow abduction: (**A**) identification of the phases according to the velocity: red (positive) for the concentric phase, green (close to 0 m/s) for the isometric phase, and blue (negative) for the eccentric phase; (**B**) parameters of force by repetition and movement phases (example of slow shoulder abduction).

Once the phases were determined, the TUT and force parameters were calculated. The TUTs calculated were concentric TUT, isometric TUT, eccentric TUT, and single repetition TUT as the sum of concentric, isometric, and eccentric TUT during 1 repetition. The analysed force parameters (Newton) were tension at 50% and 80% in each phase (measured as 50% and 80% of the maximum elongation of each phase, since the elongation at the end of the concentric phase was generally greater than the beginning of the eccentric phase) and maximum tension obtained (Figure 2A). The means across the 10 repetitions for each parameter were calculated. Furthermore, based on the elastic band elongation percentage, the maximum estimated force for each exercise and scenario was calculated, based on the information supplied by the manufacturer [32]. Elastic band elongation was calculated by subtracting the initial length at rest (i.e., 40 cm) from the length of the elastic band at the end of the ROM (measured with the linear encoder).

2.4. Statistical Analysis

Participant characteristics, force, and TUTs (Newtons (N) or seconds (s)), respectively, for each phase are presented as average (SD) and 95% confidence intervals (CIs). Mean between series was used for analysis. The degree of compliance with the expected TUTs per phase and total was analysed by subject and repetition, considering the obtained TUT as 'fulfilled' whenever the error was below 10% with respect to the prescribed TUT. This analysis is shown by frequencies; TUTs of the repetitions were subsequently either in range, exceeded the prescribed TUT, or did not reach the prescribed TUT.

Paired *t*-tests were used to analyse differences between the maximum force obtained and the maximum estimated force per scenario and exercise, and Cohen's *d* was calculated to evaluate the effect size (d > 0.2: trivial, 0.2–0.5: small, 0.5–0.8: medium, and >0.8: large) [33]. All analyses were performed using SPSS (version 25; SPSS Inc, Chicago, IL, USA).

3. Results

3.1. TUTs

Table 1 shows average TUT values for the fast, slow, and restricted ROM scenarios for shoulder abduction and knee extension. The mean of total TUTs per repetition in the fast abduction scenario was 4.07 s. Contraction phase means were 0.95 s for concentric, 1.92 s for isometric, and 1.19 s for eccentric TUTs representing, respectively, 24%, 47%, and 29% of the total TUT. The slow abduction scenario showed a mean of total TUT of 8.5 s. Contraction phase percentages were 34% for concentric, 21% for isometric, and 45% for eccentric of the total TUT. The mean corresponding to total TUTs of restricted abduction ROM scenario was 5.45 s. Contraction phase percentages were 30% for concentric, 33% for isometric, and 37% for eccentric of the total TUT. The mean TUT values obtained on the contraction phase for knee extension scenarios were very similar to those obtained in shoulder abduction scenarios.

Table 1. TUT parameters (in seconds) by scenario and phase for shoulder abduction and knee extension.

	Fast Scenario Mean (SD); 95% CI	Slow Scenario Mean (SD); 95% CI	Restricted ROM Scenario Mean (SD); 95% CI
Shoulder ABD			
Concentric time	0.95 (0.12); 0.92–1.02	2.95 (0.14); 2.9–3.01	1.62 (0.17); 1.56–1.69
Isometric time	1.92 (0.22); 1.86–2.03	1.81 (0.12); 1.76–1.85	1.82 (0.19); 1.75–1.89
Eccentric time	1.19 (0.16); 0.95–1.21	3.74 (0.22); 3.65–3.82	2.01 (0.21); 1.93–2.09
Total time	4.07 (0.24); 3.53–4.13	8.5 (0.23); 8.41–8.58	5.45 (0.41); 5.3–5.61
Knee extension			
Concentric time	0.93 (0.11); 0.89–1.05	2.73 (0.18); 2.66–2.79	1.63 (0.15); 1.57–1.68
Isometric time	2.01 (0.21); 1.95–2.08	2.07 (0.17); 2.01–2.13	1.9 (0.17); 1.83–1.96
Eccentric time	1.20 (0.17); 0.96–1.24	3.68 (0.33); 3.56–3.81	1.97 (0.19); 1.9–2.04
Total time	4.15 (0.20); 3.97–4.23	8.48 (0.29); 8.37–8.59	5.49 (0.2); 5.41–5.57

SD = standard deviation; CI = confidence interval; ABD = abduction.

3.1.1. Shoulder Abduction

Figures 3–5 illustrate the degree of compliance of TUTs in each repetition per contraction phase for the three shoulder abduction scenarios. In the concentric phase of the fast abduction scenario (Figure 3A), 344 of 580 of the repetitions were in range (59.3%), although the degree of compliance was lower in the first repetition of each set (6 and 8 of 29 repetitions in range in set 1 and 2, respectively). Results concerning the isometric phase were similar (372/580; 64.1% of the repetitions). In contrast, in the eccentric phase, the degree of compliance was lower (151/580; 26% of the repetitions in range), with 70.0% of the repetitions performed longer (in time) than expected. However, total TUTs showed a high level of compliance (536/580; 92.4% of the repetitions in range). For the slow abduction scenario (Figure 4), the degree of compliance showed a similar behaviour per phase to the fast scenario, with better compliance in the concentric and isometric phases with respect to the eccentric ones. Even so, the number of repetitions in range for the isometric phase (247/580; 42.6%) and the total phase (410/580; 70.7%) were lower than in the fast scenario. Results concerning the restricted ROM scenario (Figure 5) were in line with the two previous scenarios since the degree of compliance (repetitions in range) was better for concentric (269/580; 46.4%) and isometric (235/580; 40.5%) phases than for the eccentric phase (59/580; 10.2%). Finally, as in the two previous scenarios, the restricted ROM scenario showed better degrees of compliance for concentric (269/580; 46.4%) and isometric (235/580; 40.5%) phases than for the eccentric phase (59/580; 10.2%). These values, alongside the total TUTs (340/580; 58.6%), were, nevertheless, lower than in both previous scenarios. Furthermore, whilst the repetitions out of range tended to be performed in less time than expected for the fast and slow abduction scenarios (179/580; 30.9% and 136/580; 23.4%, respectively), performing beyond the expected time was the general tendency for the restricted ROM scenario (235/580; 40.5%).

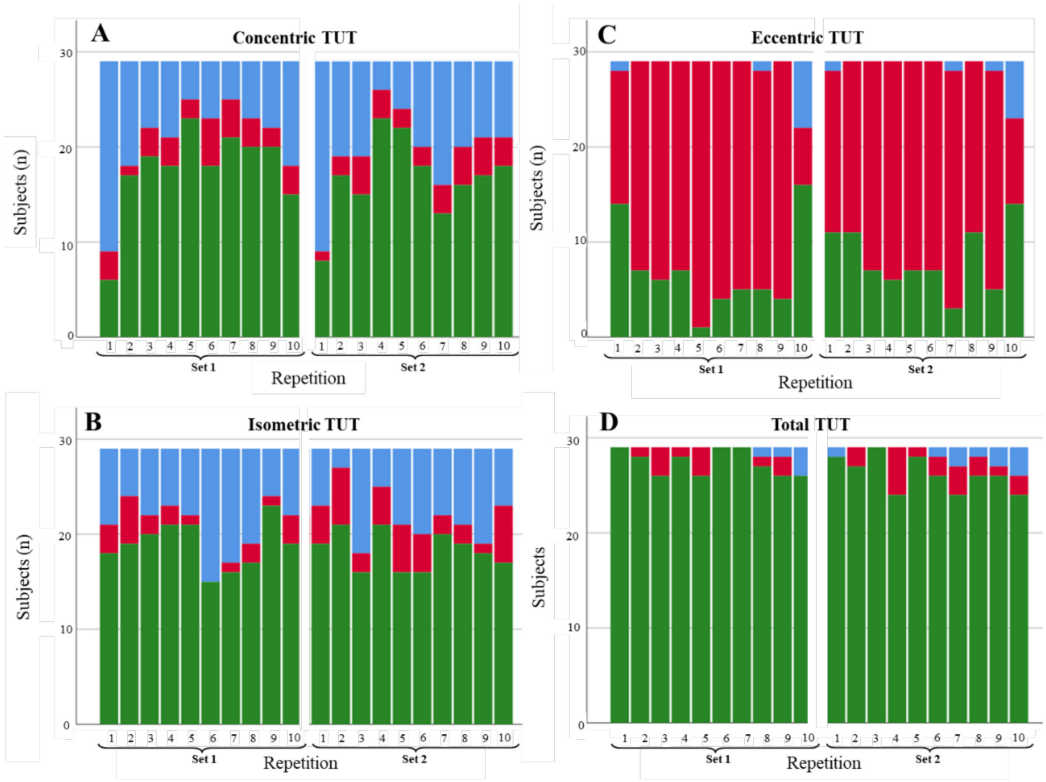

Figure 3. Degree of compliance of the TUTs for the fast abduction scenario by contraction phase: (**A**) concentric, (**B**) isometric, (**C**) eccentric, and (**D**) total. TUTs: in range = green; performed in less time than expected = blue; performed in more time than expected = red.

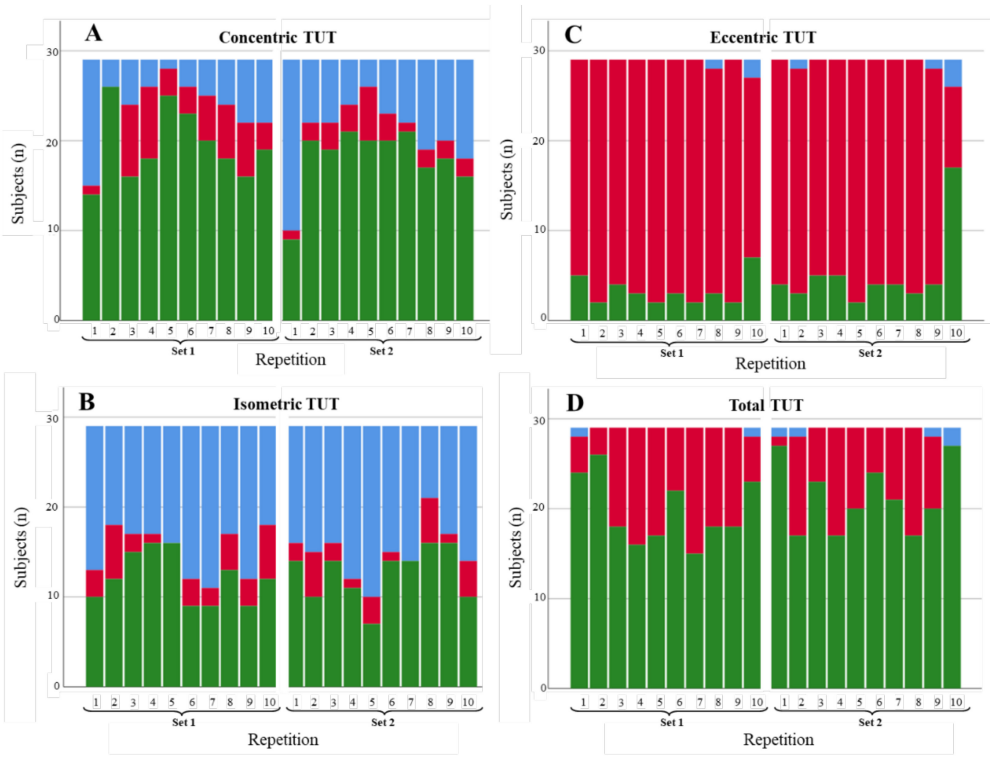

Figure 4. Degree of compliance of the TUTs for the slow abduction scenario by contraction phase: (**A**) concentric, (**B**) isometric, (**C**) eccentric, and (**D**) total. TUTs: in range = green; performed in less time than expected = blue; performed in more time than expected = red.

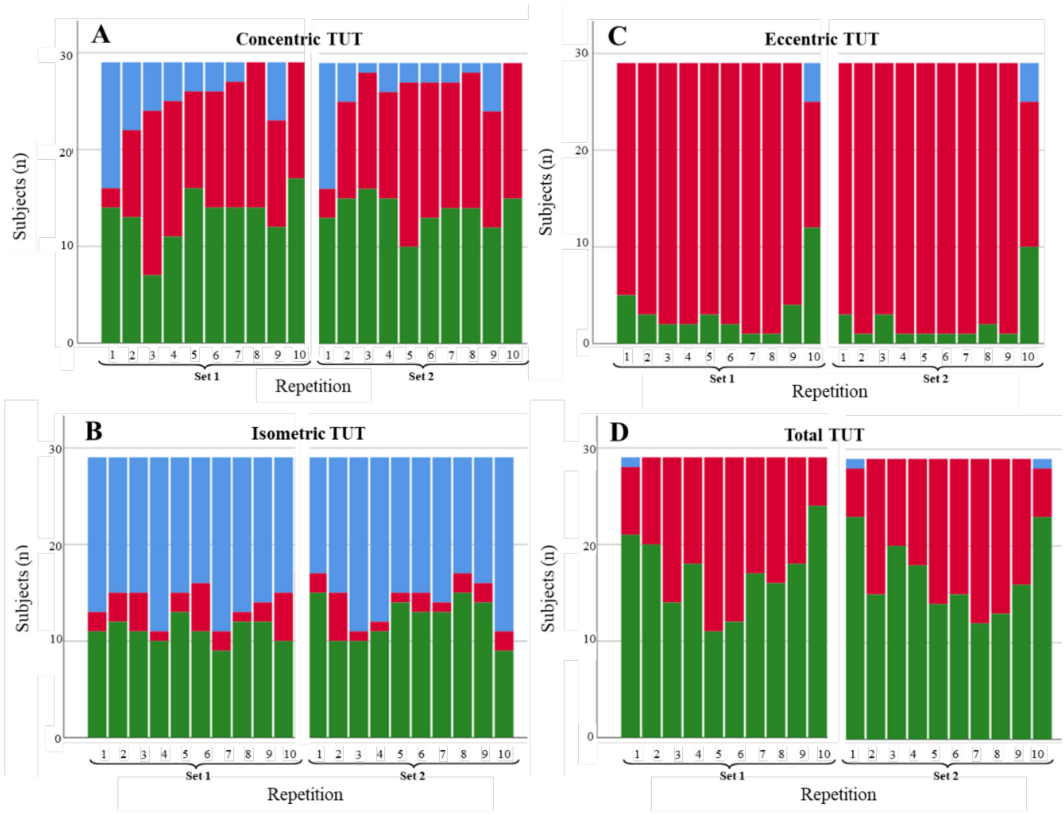

Figure 5. Degree of compliance of the TUTs for the restricted abduction ROM scenario by contraction phase: (**A**) concentric, (**B**) isometric, (**C**) eccentric, and (**D**) total. TUTs: in range = green; performed in less time than expected = blue; performed in more time than expected = red.

3.1.2. Knee Extension

Figures 6–8 illustrate the degree of compliance of TUTs in each repetition per contraction phase for the three knee extension scenarios. Along the same lines as shoulder abduction, the degree of compliance (repetitions in range) in the fast extension scenario was better for concentric (324/580; 55.9%) and isometric (395/580; 68.1%) phases than for the eccentric phase (147/580; 25.3%). Again, the total TUTs showed a high degree of compliance values (520/580; 89.6%). The slow extension scenario showed a similar pattern to the fast scenario across phases (with better degrees of compliance in the concentric and isometric phases than in the eccentric phase), but the values of the degree of compliance were slightly lower, with a number of repetitions with TUTs in the range of 258/580, 44.4%; 293/580, 50.5%; 101/580, 17.4%, respectively. In addition, the isometric phase showed (especially in series 1) a high number of repetitions performed in more time than expected (193/580; 33.3%). Finally, the restricted extension ROM scenario performed slightly differently than the extant two scenarios. Whereas the concentric and isometric phases had, again, better degrees of compliance than the eccentric phase (295/580; 50.9% and 359/580; 61.9% versus 52/580; 8.9%), the percentage of repetitions in range for the total TUTs was lower than in some phases (299/580; 51.5%).

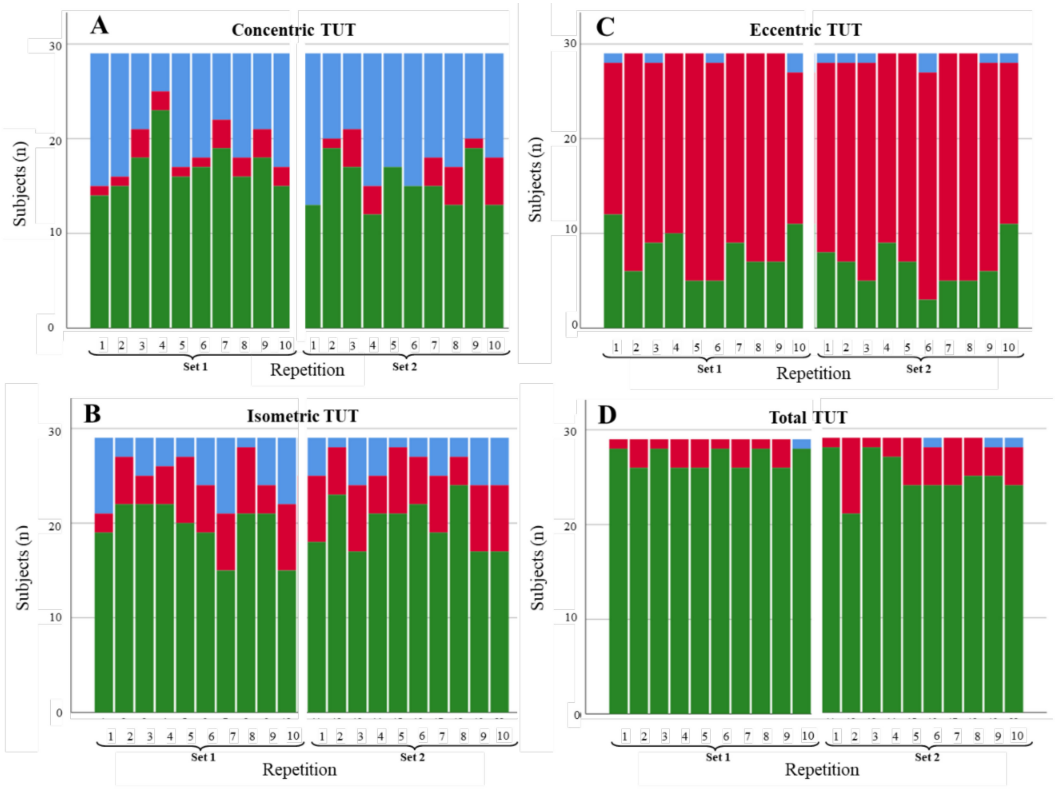

Figure 6. Degree of compliance of TUTs for the fast extension scenario by contraction phase: (**A**) concentric, (**B**) isometric, (**C**) eccentric, and (**D**) total. TUTs: in range = green; performed in less time than expected = blue; performed in more time than expected = red.

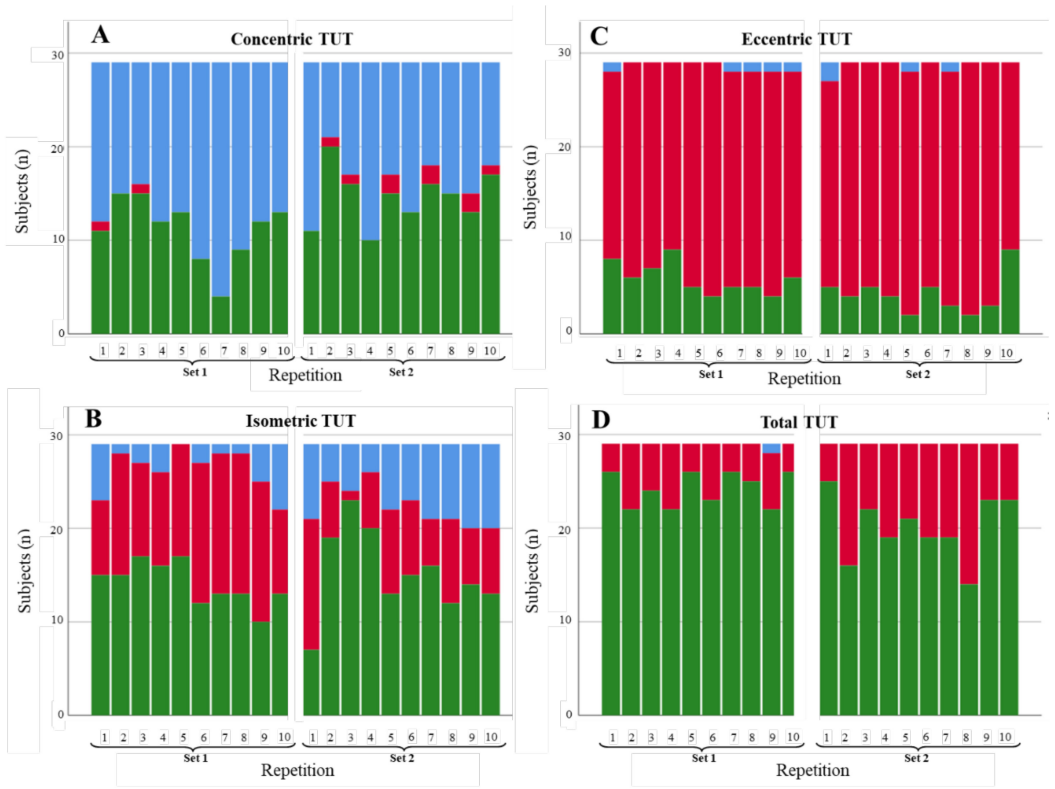

Figure 7. Degree of compliance of TUTs for the slow extension scenario by contraction phase: (**A**) concentric, (**B**) isometric, (**C**) eccentric, and (**D**) total. TUTs: in range = green; performed in less time than expected = blue; performed in more time than expected = red.

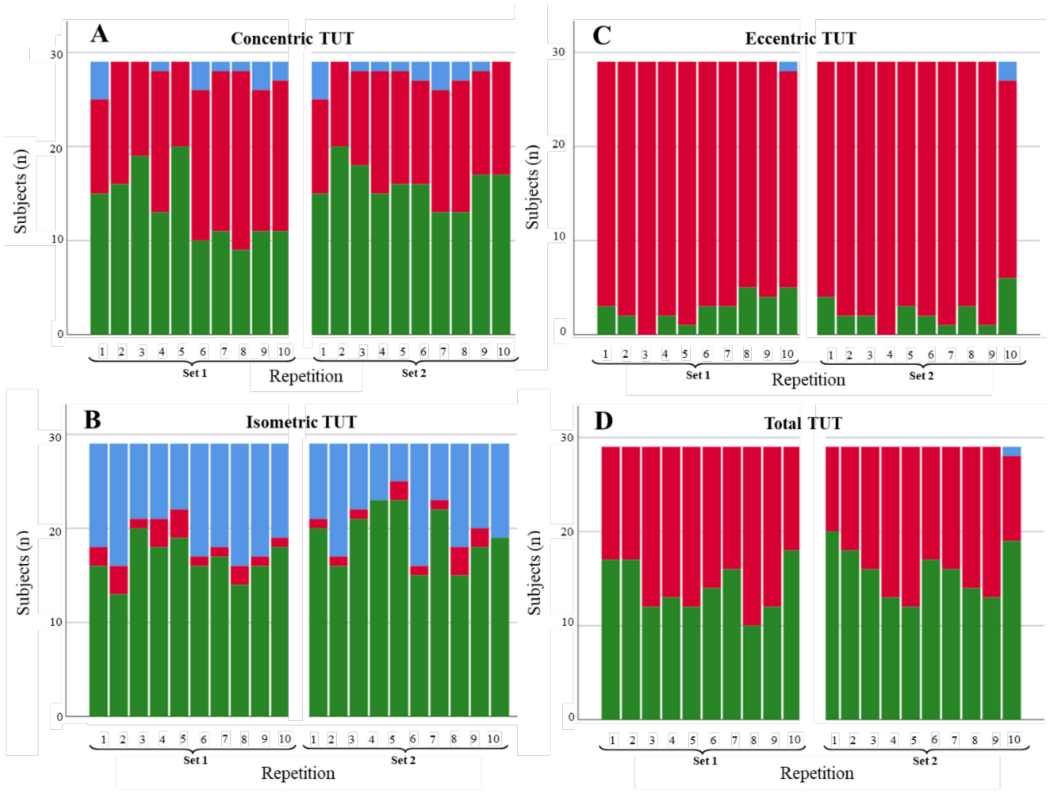

Figure 8. Degree of compliance of the TUTs for the restricted extension ROM scenario by contraction phase: (**A**) concentric, (**B**) isometric, (**C**) eccentric, and (**D**) total. TUTs: in range = green; performed in less time than expected = blue; performed in more time than expected = red.

3.2. Force

Table 2 shows the mean force values registered in three scenarios for shoulder abduction and knee extension in Newtons (N). For the fast abduction scenario, force at 50% of the concentric movement was 18.03 N, representing 64% of the maximum force (28.14 N), while at 80% of the concentric movement, the force was 23.82 N, representing 85% of the maximum force. The aforementioned results were similar to those obtained in the eccentric contraction phase, although they were slightly lower. Values obtained for the slow scenario were also very close to those obtained for the fast scenario, showing differences below 0.40 N. For the restricted ROM scenario, results were roughly half of the values obtained in the other scenarios. On the other hand, as expected, the force values obtained for the knee scenarios were higher than those obtained in the shoulder abduction scenarios. At 50% and 80% of the concentric movement, the force was, respectively, 70% and 89% of the maximum force (70.12 N). These results were similar to those obtained in the eccentric contraction phase, although they were slightly lower, as in the shoulder abduction scenarios. Values obtained for the slow scenario were also very close to those obtained for the fast scenario, with differences below 1.01 N. Again, the restricted ROM scenario showed force values around half of the values from the other two scenarios.

Table 2. Force parameters (Newtons) by scenario for shoulder abduction and knee extension.

	Fast Scenario Mean (SD); 95% CI	**Slow Scenario Mean (SD); 95% CI**	**Restricted ROM Scenario Mean (SD); 95% CI**
Shoulder abduction			
50% Concentric	18.03 (2.37); 17.13–18.93	17.78 (2.08); 16.98–18.57	13.34 (2.32); 8.72–10.49
80% Concentric	23.82 (2.88); 22.73–24.92	23.43 (2.53); 22.46–24.39	13.34 (3.01); 12.19–14.48
Maximum	28.14 (3.3); 26.89–29.39	27.74 (2.84); 26.66–28.82	15.72 (3.29); 14.47–16.97
80% Eccentric	21.03 (2.56); 20.06–22	21.17 (2.22); 20.32–22.01	11.88 (2.59); 10.9–12.87
50% Eccentric	14.78 (2.02); 14.01–15.55	14.98 (1.78); 14.3–15.66	7.84 (1.81); 7.15–8.52

Table 2. *Cont.*

	Fast Scenario Mean (SD); 95% CI	Slow Scenario Mean (SD); 95% CI	Restricted ROM Scenario Mean (SD); 95% CI
Knee extension			
50% Concentric	49.36 (2.75); 48.31–50.4	49.64 (3.28); 48.4–50.89	34.67 (3.69); 33.27–36.08
80% Concentric	62.49 (3.37); 61.21–63.77	62.6 (3.97); 61.09–64.11	45.76 (4.49); 44.05–47.46
Maximum	70.12 (4.28); 68.49–71.75	70.96 (5.04); 69.05–72.88	51.33 (4.91); 49.47–53.2
80% Eccentric	55.80 (3.33); 54.53–57.06	56.78 (4.12); 55.21–58.34	41.5 (4.25); 39.88–43.11
50% Eccentric	40.91 (2.51); 39.96–41.87	41.92 (3.03); 40.77–43.07	28.73 (3.26); 27.49–29.97

SD = standard deviation; CI = confidence interval.

Differences between Estimated and Real Force

Table 3 shows the differences, per exercise and scenario, between the estimated maximum force (i.e., reference values provided by the manufacturer) and the real maximum force obtained. All the obtained maximum force values were lower than the expected values, with differences ranging from 34.1% to 38.5% for the shoulder abduction and from 24.8% to 29.5% for the knee extension. All differences showed large effect sizes (Cohen's $d > 2.48$).

Table 3. Differences between estimated maximum force (Newtons) and real maximum force (Newtons) per exercise and scenario.

	Estimated Maximum Force Mean (SD); 95% CI	Force Differences (Estimated Force Minus Real Force)	
		Mean (%); 95% CI	Effect Size (95% CI)
Shoulder abduction			
Fast scenario	44.77 (2.89); 43.67/45.87	17.03 (38.1%); 16.35/17.71 *	5.94 (4.66 to 7.70
Slow scenario	45.75 (3.59); 44.39/47.12	17.61 (38.5%); 16.92/18.31 *	5.10 (3.94 to 6.72)
45° scenario	23.85 (3.28); 22.6/25.1	8.13 (34.1%); 7.49/8.78 *	2.48 (1.85 to 2.94)
Knee extension			
Fast scenario	98.43 (5.91); 96.18/100.68	27.47 (27.9%); 25.71/29.22 *	5.01 (4.32 to 5.80)
Slow scenario	99.41 (5.42); 97.35/101.47	29.29 (29.5%); 27.71/30.88 *	6.01 (4.97 to 6.94)
45° scenario	68.22 (5.09); 66.29/70.16	16.89 (24.8%); 15.86/17.92 *	3.38 (2.57 to 4.14)

SD = standard deviation; CI = confidence interval. * Significant differences at $p < 0.001$.

4. Discussion

The aims of this study were to evaluate the degree of compliance with the prescription of TUTs for three different scenarios of two exercises, and the comparison of the force values obtained versus the estimated values. Four important findings emerged: first, the concentric and isometric phases showed a higher degree of compliance for their TUTs than the eccentric phase TUTs for all scenarios of both exercises, whereas the degree of compliance was higher for the total TUT than for the phases' TUTs; second, the eccentric phase showed a general tendency to be developed for longer time periods than prescribed; third, the fast scenario showed a higher degree of compliance for the isometric phase TUTs and total TUTs than the other two scenarios in both exercises; fourth, the force of the elastic bands tends to be overestimated according to the estimates of the manufacturers.

To our knowledge, this is the first study to examine the degree of compliance on the TUTs of common training exercises with elastic bands per contraction phase. Our findings showed differences in the percentage of repetitions with TUTs in range across the different phases, with a degree of compliance higher for the concentric and isometric phases compared with the eccentric phase for all scenarios and exercises. In addition, the results stemming from the eccentric phase consistently showed how subjects usually tend to perform this phase for a longer time period than prescribed: it may be due to the fact that the eccentric phase corresponds to the return phase and the subjects have

to resist the traction force of the elastic band. Thus, the possible fear of performing it faster than prescribed may result in a reactive overaction. Therefore, our results could help health and training professionals who guide exercises with elastic bands, so that they specifically highlight the importance of complying with the TUT for this phase and especially emphasize not performing it slower than the indicated TUT.

On the other hand, the total TUT showed a degree of compliance generally higher than TUTs for each one of the phases. Since previous studies have used this parameter [27,34] instead of TUTs by phases to evaluate compliance, our findings would indicate that the use of the total TUT parameter for this purpose may be an error by masking different degrees of compliance across phases.

The isometric phase showed a better degree of compliance for the fast scenario than for the slow or restricted scenarios. In all three scenarios, the prescribed TUT for the isometric phase was 2 s, so a difference in the degree of compliance across scenarios is unexpected, given that the TUT remains the same. In addition, except for the slow knee extension, those repetitions in which the TUT was not in range tended to be performed in less time than prescribed, that is, the isometric phase lasted less than 1.8 s. This may be due to the fact that the subjects tend to become fatigued when holding the position and traction of the elastic band, especially in the shoulder, and tend to start the return (i.e., eccentric phase) earlier than prescribed. Our findings would, therefore, suggest paying special attention to maintaining the prescribed TUT of the isometric phase.

On another note, in relation to the force analysis, our findings show a clear overestimation of the force data provided by the manufacturer, since the force obtained was at least 25% less than estimated. Previously, Uchida et al. [25] showed similar differences to ours, under laboratory conditions, in the comparisons of the obtained versus estimated force values, finding difference percentages of 22% for the blue elastic band and 42% for the golden [25]. Thus, our findings confirm that the values proposed by the manufacturer should be used cautiously since the tension (i.e., intensity) applied by the elastic band is actually lower. Furthermore, according to our knowledge, our study is the first to explore and propose values of 50% and 80% of the ROM of two of the most commonly used exercises for training with elastic bands.

To the best of our knowledge, no previous studies have examined the exercises of shoulder abduction and knee extension with elastic bands in the training scenarios proposed in the literature (i.e., fast or slow execution or performance with restricted ROM). Furthermore, the use of a reference measure to evaluate velocity and tension (linear encoder and force gauge, respectively), and their simultaneous synchronisation could be considered one of the main strengths of the current study. Despite its novel findings, this study was subject to some limitations: first, analyses were conducted on healthy subjects, mainly males, without recent injuries, limiting the generalisation to other populations. Thus, TUTs for fast or slow scenarios could be different for athletes from sports with a predominant use of a particular lower or upper limb (e.g., soccer or baseball, respectively) or between sexes. Additionally, the restricted ROM scenario simulates a situation in which the person has a condition hindering the movement of the segment throughout the ROM. Since we have studied all three scenarios at the same time, we understand that each scenario can be of paramount importance to each target population. Therefore, future studies should examine TUTs in specific populations for which each scenario is the main recommendation. Additionally, measures were made in a controlled environment. Although our study is a first approach to the analysis of the degree of compliance with TUTs and force carried out under the supervision of a physiotherapist, future studies should examine the degree of compliance in a home environment, under no supervision, after familiarisation with the exercises and scenarios.

5. Conclusions

Our study provides insight into the degree of compliance with the TUTs for the different phases of two of the most commonly used training exercises with elastic bands,

showing that the eccentric phase has a lower degree of compliance than the concentric and isometric phases and that the total TUT would not be advisable to use since it can mask what happened in the different phases. In addition, the analysis of force for the elastic bands used in our study revealed that the values described by the manufacturer are usually overestimated.

Author Contributions: F.M.-M. and R.M.-S.A. designed the study and conducted the literature search. J.G.-R., N.M.-S. and R.M.-S.A. were responsible for data acquisition. A.C.-D.P., F.M.-M. and M.G.-S. were involved in data analysis and interpretation. J.G.-R., F.M.-M. and R.M.-S.A. were involved in writing the manuscript. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Institutional Review Board of UNIVERSITY OF VALENCIA (SPAIN) (Protocol Code 1239215, 7 February 2020).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The datasets generated during and/or analysed during the current study are available from the corresponding authors on reasonable request.

Conflicts of Interest: The authors declare no conflict of interest.

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