FIGUR8

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Precision in Motion: How FIGUR8's bioMotion Assessment Platform Redefines Musculoskeletal Care

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Table of Contents

Introduction

FIGUR8 stands at the forefront of revolutionizing musculoskeletal (MSK) health management by seamlessly merging biomechanics research and state of the art technology with AI-enabled data insights. The result of this merging between research and advanced technology is the bioMotion Assessment Platform (bMAP), a portable biomechanics lab that produces cutting-edge assessments, activities and unparalleled bioMotion reporting. Designed to extract the most relevant biomarkers crucial for understanding injuries and facilitating recovery, the bMAP sits at the foundation of ensuring objective digital measurement of the severity of, and the improvement and recovery from a MSK injury.

The vision of FIGUR8 began as a collaboration between MIT scientists, Mass General Hospital Sports Medicine and the Boston Red Sox as a search for a better way to build an on-body biomechanics solution to optimize performance of elite athletes. Spun off from the MIT Media Lab, FIGUR8 builds on top of decades of research in sports science and has created a portable biomechanics lab solution through a completely novel, easy-to-use, accessible platform that provides objective, actionable data around MSK function, for use at any point-of-care. By arming individuals and care teams with actionable, data-driven insights on MSK health, FIGUR8 endeavors to redefine the standard of care for MSK conditions, catalyzing a transformative shift in health towards precise and personalized care.

In an era marked by over 20,000 peer-reviewed publications in MSK clinical research from the gold-standard biomechanics lab, the field is ripe with invaluable insights into better understanding injury risk, severity, and recovery. Yet, the prohibitive costs associated with traditional biomechanics labs hinder widespread access to this wealth of knowledge, constraining effective MSK health management for all.

The FIGUR8 solution was built to directly address known data access constraints in MSK health management. These known constraints are:

- Steep cost, time and space constraints of a traditional biomechanics lab;
- Specialized expertise to manage and summarize motion data; and
- Integration into clinical workflows.

This compendium provides an overview of the scientific principles underlying an exceptionally scalable point-of-care solution aimed at delivering objective data insights into MSK health, the bioMotion Assessment Platform (bMAP), developed by FIGUR8.

The following key topics will be covered:

1. Validation and verification research behind the bMAP;
2. Design of FIGUR8's bioMotion Assessments, including activity and metric selection based on comprehensive literature reviews; and
3. Results and impact of bMAP specific to how a clinician can leverage FIGUR8 data insights to guide clinical decision-making.

Methods

1. The validation and verification methodology behind the bioMotion Assessment Platform (bMAP)

FIGUR8 is the innovation leader in musculoskeletal (MSK) biometrics, redefining the way MSK health is measured to deliver improved clinical and financial outcomes. The bioMotion Assessment Platform (bMAP), developed and designed by FIGUR8, is the first practical solution for measuring MSK function precisely and objectively, at any point-of-care. The technology is a combination of hardware (i.e. bluetooth enabled sensors), software and cloud-based analytics that has set a new data standard for MSK health.

To develop the platform, a portable, wearable sensor fusion solution was designed that can generate the same level of signal accuracy as a gold standard biomechanics lab. The following section will describe our system validation and verification process for the bMAP.©

FIGUR8's sensor fusion solution outputs dynamic joint motion and muscle function measurements from two main sensing modalities: the inertial measurement unit (IMU) sensor network to reconstruct joint motion across multiple body segments, and the surface mechanomyography (sMMG) sensors to measure muscle function. The sensor fusion solution was validated with the gold standard biomechanics lab system listed in Table 1.1.

Table 1.1: *Validation methodologies, hardware, and software systems used to validate the biomechanics data output from FIGUR8's bMAP.*

	FIGUR8	**Validation Tools**		
Biomechanics data	**Hardware**	**Method**	**Hardware**	**Software**
Joint Motion	9-axis Inertial Measurement Unit network (up to 7 devices)	Optical Marker-based Motion Capturing (MOCAP)	8x Vicon Vero 2.2 Camera 330Hz @ 2.2MP Vicon Nexus 2.16	Visual3D from C-Motion
Muscle Function	surface Mechanomyography (sMMG)	Electromyography (EMG)	Delsys Trigno Avanti EMG Kit	EMGworks Trigno Discover
Timing of Force Output from Muscle Contraction	surface Mechanomyography (sMMG)	Handheld Dynamometer (HHD)	Lafayette Hand-Held Dynamometer	N/A

Each validation test included 15 subjects, recruited from an independent recruiting agency to create a normative healthy dataset and go through the accuracy validation. Subject cohorts were chosen for even gender balance, broad age distribution from 18 - 65, and broad BMI distribution within the normal-to-overweight BMI range. After the accuracy validation is completed, a reliability test is performed, which includes the analysis of an intra/inter variability test/re-test[1,2] and comparison of the results with the normative health dataset.

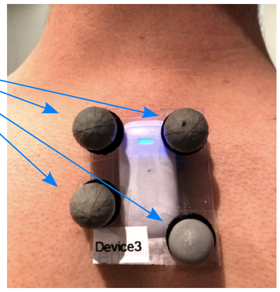
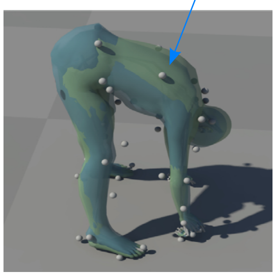
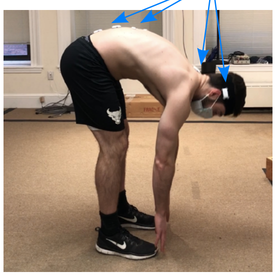
Joint motion measurement validation

A network of 9-axis IMU sensors are used to reconstruct joint motion during activity. The data output allows for calculation of joint motion in all three planes.

Figure 1.1. *An illustration of how to use two IMUs to measure motion of the knee joint. In this image, only the sagittal plane is illustrated.*

Two accuracy validation methods are utilized, listed in Table 1.2: device accuracy and anatomical accuracy.

Table 1.2: *Accuracy Validation of joint motion measurement between FIGUR8's IMU system and the VICON optical marker-based MOCAP system.*

Validation	Objective	Method	
Device Accuracy	Validate IMU on-body placement and 3D movement tracking against optical motion capturing (MOCAP) of the same location	 Vicon markers on custom rigid device marker plate	
Anatomical Accuracy	Validate the accuracy of FIGUR8's joint angles against those generated from the MOCAP data in Visual3D. The Visual3D anatomical model used is based on articles published by the ISB on recommendations for the definitions of joint centers[3]	VICON markers on-body  	FIGUR8 devices on-body  

Device accuracy and anatomical accuracy are tested and validated before specific assessments are designed. The tests ensure placement of the sensors will generate accurate results within the error margin that's acceptable from human body variations, such as soft tissue movements. A model based on Figure 1.2 is an example plot of the side-by-side comparison of the FIGUR8's bMAP joint motion output against the VICON system's joint motion output.

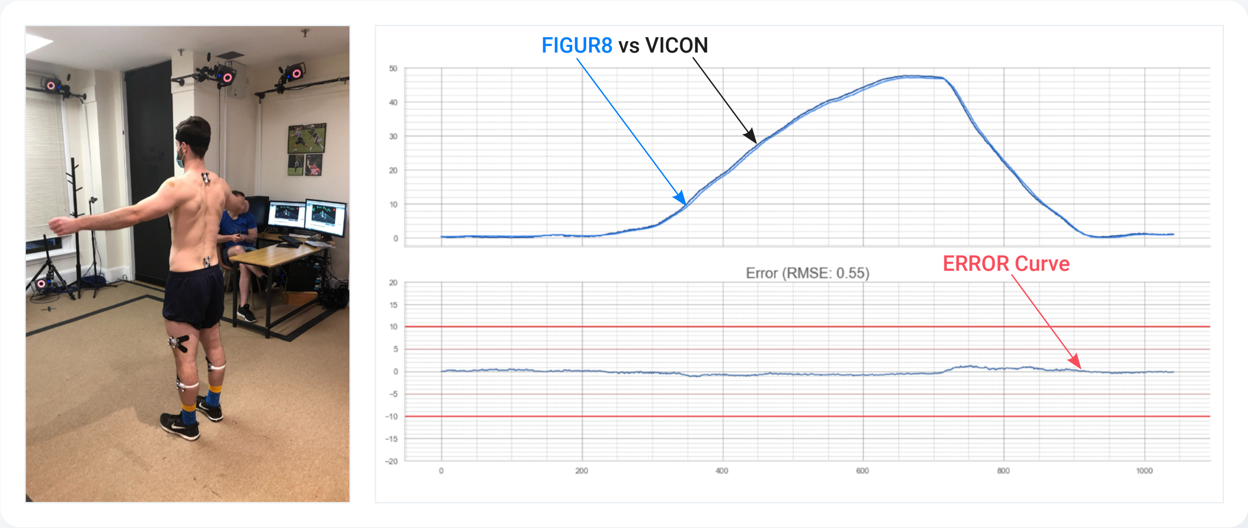


Figure 1.2. *Side-by-side comparison of the FIGUR8 system's joint motion output against VICON system's joint motion output.*[3]

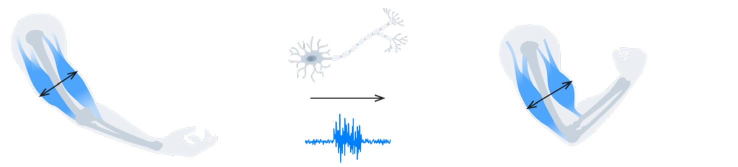
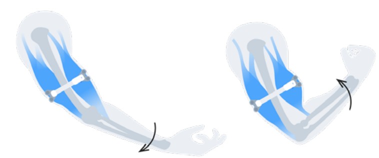
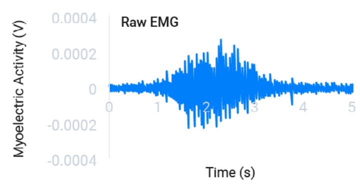
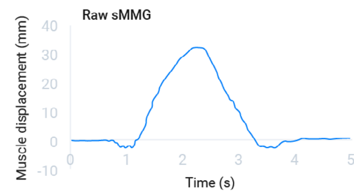
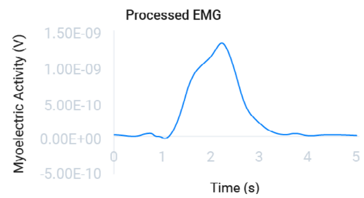
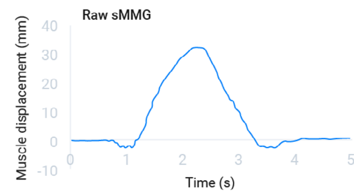
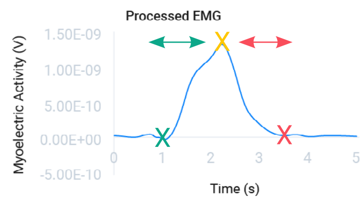
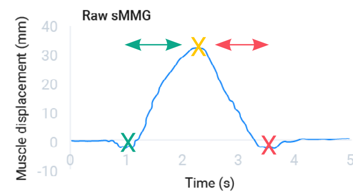
After the foundational sensor accuracy validation has been completed, bioMotion Assessment design begins. The bioMotion Assessment is a series of validated clinical tests to measure MSK function specific to an anatomical region. FIGUR8 Enabled clinicians choose from a series of bioMotion Assessments when completing an evaluation with the bMAP. The design of each bioMotion Assessment available through the bMAP starts with validating the sensor accuracy while performing dynamic physical activities.

Muscle function measurement validation

The surface mechanomyography (sMMG) sensors used in the bMAP measure muscle function by quantifying muscle contraction timing, amplitude, and duration. Validated with commercially available EMGs (Table 1.3 (bottom)), sMMG sensors are capable of recording volumetric change with a sensitivity of 100 micrometers, or about the width of a human hair. In the system design, muscle amplitude is reported between specific time points relevant to the movement.

The benefit of sMMG measurement compared with traditional electromyography (EMG) measurements is the ease of application without the need for skin prepping and patient discomfort, as well as the ease of interpretation, without extra signal processing. The raw sMMG signal can easily indicate side by side imbalance and neuromuscular control.

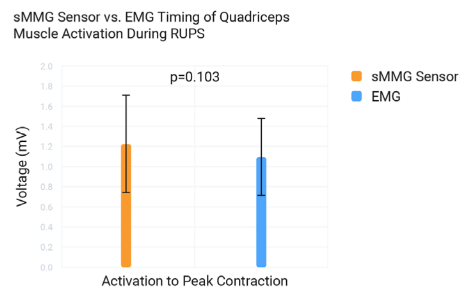
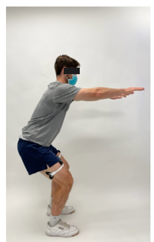
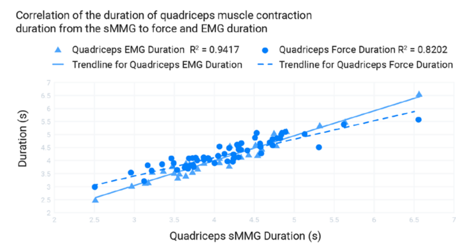
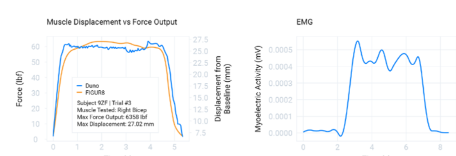
Table 1.3: *(top) Illustration of how sMMG sensors are placed on muscle bulks to capture the contraction amplitude, timing, and stability. (bottom) Example of data analysis steps for comparison between electromyography (EMG) and surface mechanography (sMMG) timing during a bilateral squat task.*

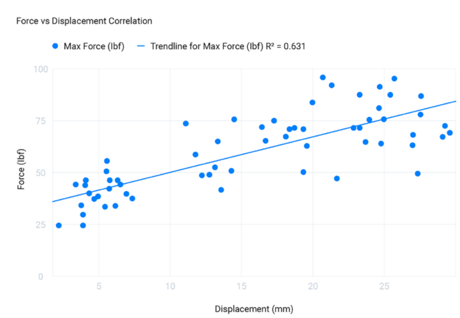
		
		
1) Signal Processing:	6^{th} order low-pass Butterworth filter (3Hz) and rectified TKEO function	No signal processing applied
		
2) Time Point Identification:	Activation threshold set 3 standard deviations above resting trial mean for each modality (Solonik et al., 2010)	
Variables: X Activation time X Deactivation time X Peak contraction <-> squat descent <-> squat ascent		

FIGUR8's sMMG sensor measurement provides a wide range of applications that are clinically relevant through collection of biometric data including muscle contraction timing, amplitude, and stability.

Table 1.4 and 1.5 (below) list research topics that have been conducted by the biomechanics team at FIGUR8 as well as collaborators from Massachusetts General Hospital's Sports Medicine Program. The research showcases the versatility of clinical relevance with sMMG's output data. Table 1.5 displays the value of bMAP as a system of IMU and sMMG sensors working in concert to define clear stability metrics, which are an indicator of whether or not an individual is improving, regressing, or stabilizing in their MSK health, as well as a clear reference range in order to understand if an individual is healthy or unhealthy.

Table 1.4: *Topics of research conducted by FIGUR8 and collaborators from Mass General Hospital's Sports Medicine Program using sMMG sensor.*

<table>
<tr><th>Validation</th><th colspan="3">Objective</th><th>Summary</th></tr>
<tr><td rowspan="3">Timing Accuracy[4,9]</td><td colspan="3">Comparison of FIGUR8 sMMG sensor muscle activity timing to EMG and force dynamometry muscle timing</td><td>The findings reveal similarities in time signatures between the sMMG, EMG, and dynamometry sensors, which confirms the ability of the sMMG sensor to detect the key time points of muscle activation, peak contraction and deactivation.</td></tr>
<tr><td>
</td><td>
</td><td>
</td><td>
</td></tr>
<tr><td></td><td></td><td></td><td>
</td></tr>
<tr><td rowspan="2">Force vs Muscle Displacement[5]</td><td colspan="3">Study the relationship of sMMG sensor measurement of muscle displacement to muscle force output</td><td>Muscle displacement is significantly correlated to the force generated for maximal volitional isometric biceps contractions.</td></tr>
<tr><td colspan="3"></td><td>


</td></tr>
</table>

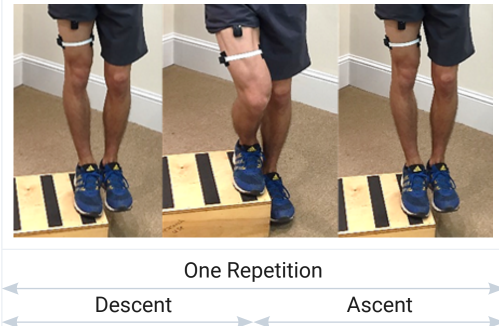
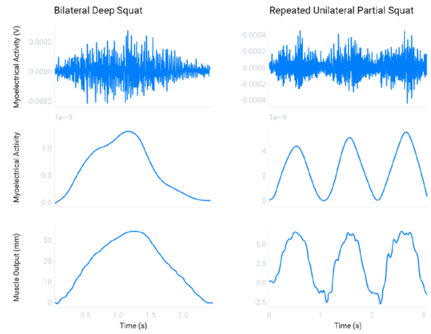
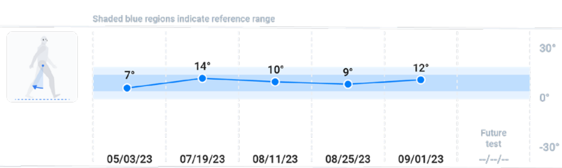
<table>
<tr><td rowspan="2">Neuromuscular Control During Screening Activities[6,7,8]</td><td>Investigate the ability of sMMG sensors to detect timing patterns of muscle contraction during neuromuscular control screening tasks.</td><td>The results support the ability of the sMMG sensor to accurately detect quadriceps contraction due to the substantial timing similarities with simultaneous EMG capture.</td></tr>
<tr><td>
</td><td>
</td></tr>
</table>

Table 1.5: *Topics of research conducted by FIGUR8 and collaborators from Mass General Hospital's Sports Medicine Program using sMMG and IMU sensor.*

<table>
<tr><th>Validation</th><th colspan="3">Objective</th><th>Summary</th></tr>
<tr><td rowspan="2">Stable metric</td><td colspan="3">To provide expected ranges for healthy individual change between assessments.</td><td rowspan="2">Expected ranges reflect 90% of the inter-assessment variability from repeated tests on healthy individuals (i.e. those without a MSK injury). Data from this study can be used to determine if an individual's MSK health is improving, regressing, or stabilizing.</td></tr>
<tr><td colspan="3">
</td></tr>
<tr><td rowspan="5">Reference Range</td><td colspan="3">To provide expected ranges for each FIGUR8 metric based on a sample of healthy individuals.</td><td rowspan="5">Expected ranges reflect 90% of the healthy population's (individuals without a MSK injury) metric output. Data from this study can be used to determine if metrics collected during an individual's FIGUR8 assessment are consistent with a reference data set collected from healthy individuals (i.e. those with a MSK injury).</td></tr>
<tr><td>Neck (n=15)</td><td>Low Back (n=19)</td><td>Knee (n=16)</td></tr>
<tr><td>age:
36.9 ± 12.5 y
height:
69.0 ± 4.1 in
weight:
166.1 ± 25.5 lbs
bmi:
24.5 ± 2.7</td><td>age:
34.1 ± 11.5 y
height:
68.4 ± 4.3 in
weight:
165.0 ± 31.7 lbs
bmi:
24.8 ± 4.3</td><td>age:
37.1 ± 12.5 y
height:
69.0 ± 4.0 in
weight:
175.4 ± 30.2 lbs
bmi:
25.8 ± 3.4</td></tr>
<tr><td>Female: 6
Male: 9</td><td>Female: 7
Male: 12</td><td>Female: 6
Male: 10</td></tr>
<tr><td colspan="3">
</td></tr>
</table>

2. The design of FIGUR8 bioMotion Assessments: capturing accurate biomarker data in minutes

The vision of FIGUR8 is to provide objective MSK data insights, accessible at every point-of-care. While turning this vision into reality, three key barriers were identified: hardware cost and accessibility, data capture speed, and system usability. Hardware accessibility issues were solved first, with the advent of the portable biomechanics lab, bMAP, described above. Subsequently, focus turned toward data analytics and reporting with usability in mind. FIGUR8 developed a clinician-facing assessment application that couples with the bMAP hardware to capture, analyze, and upload data to the cloud in a fast and usable format. This advancement in data capture and interpretation allows for access to accurate biomechanical data from any web browser via FIGUR8's web portal(Figure 2.1).

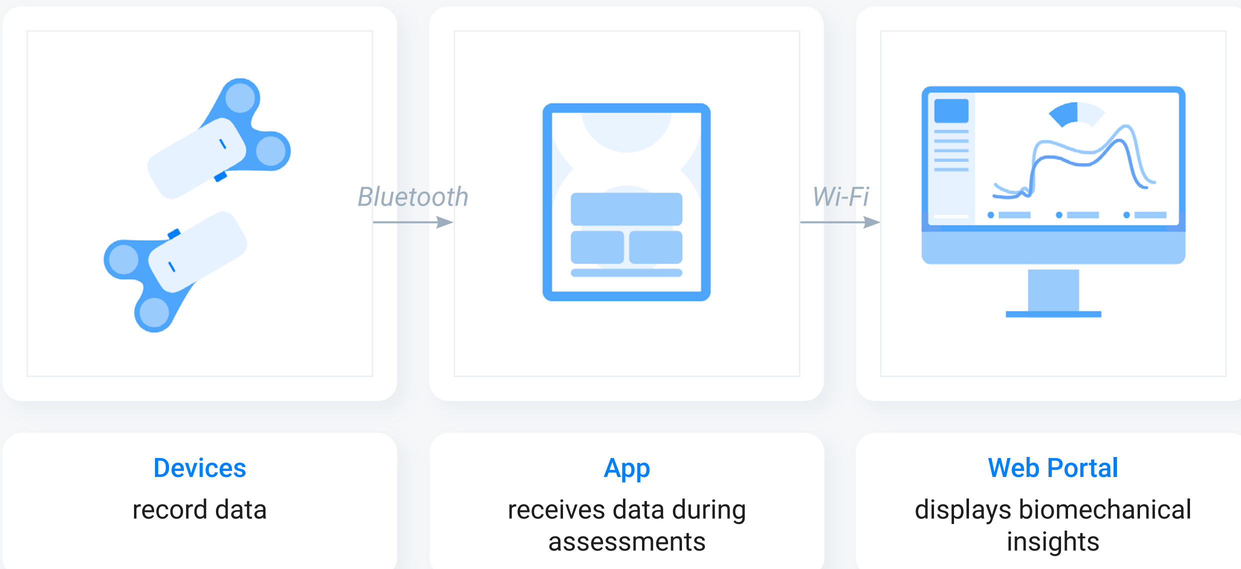


Figure 2.1. *The clinically-led workflow of a FIGUR8 bioMotion Assessment: from data collection to display.*

Tailored for clinicians, the FIGUR8 solution streamlines data collection and interpretation. By modularizing assessment procedures and leveraging specialized anatomical knowledge, clinicians can swiftly acquire actionable insights in 10% of the time required for a traditional biomechanics lab. This rapid turnaround time empowers clinicians to make informed decisions and provide timely interventions during patient evaluations, ultimately enhancing the quality of care delivered in clinical settings.

All FIGUR8 bioMotion Assessments available via bMAP go through a rigorous validation process, which includes accuracy and reliability testing, to ensure that sensor placement guidelines are optimized and data fidelity meets rigorous standards. A FIGUR8 bioMotion Assessment utilizes tailored protocols, including curated sensor configuration and a set sequence of activities, targeting distinct anatomical regions.

Key biomarkers gathered in MSK health measurement fall into the following three categories: dynamic range of motion, muscle function, and functional activities. Traditional assessment tests, such as shoulder endurance, sit-to-stand, and gait, are augmented by the FIGUR8 bMAP (Figure 2.2 (a)). The bioMotion Assessments are engineered to yield the most prevalent and clinically relevant biomarkers associated with each targeted body structure and function, based on existing biomechanics literature. This strategic focus enables users to swiftly assess biomarker data, thereby furnishing actionable insights for informed decision-making.

Currently, the bMAP offers 5 bioMotion Assessment types based on anatomical region (Figure 2.2(b)): Neck, Low Back, Knee, Upper Extremity Screen, and Lower Extremity Screen (to be released in Q2 2024).

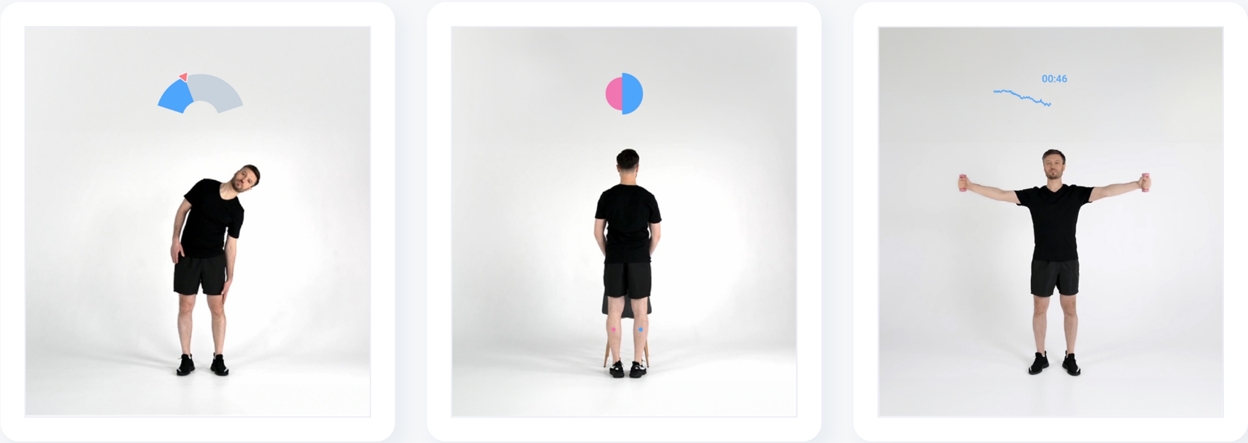


Figure 2.2(a). *Key biomarkers categories captured by FIGUR8 bioMotion Assessments: dynamic range of motion, muscle function, and functional activities.*

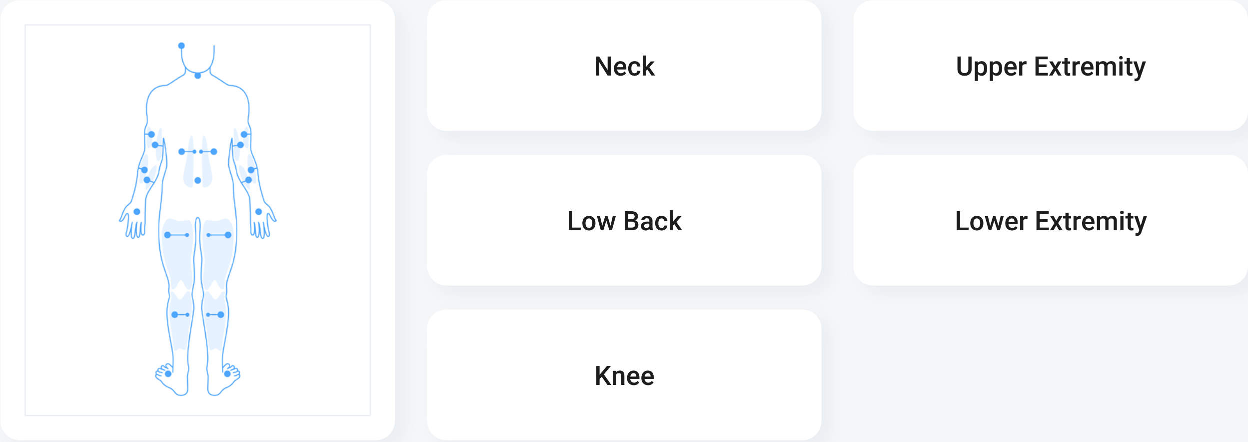


Figure 2.2(b). *Available FIGUR8 bioMotion Assessments.*

The following outlines the protocol used to develop a FIGUR8 bioMotion Assessment for evaluating a specific anatomical region in detail.

The Development of FIGUR8 bioMotion Assessment

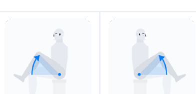
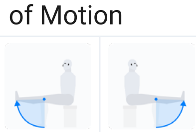
The clinical relevance of biometric data, MSK assessment activities and diagnostic categories are well-studied by the science community. Building on the foundation established by the wealth of biomechanical research, clinical expertise guided the design of FIGUR8 bioMotion Assessments to capture the known biomarkers that can best bring insights to the following diagnostic categories: injury, recovery, and workability. Table 2.1 lists the biomarker metrics in a FIGUR8 Knee bioMotion Assessment where the activities are linked to biomarkers that are validated by peer-reviewed scientific journals. These publications, put together through a literature survey as the bioMotion Assessment was designed, echo clinical best practice guidelines[10] with clinical test recommendations listed below (Figure 2.3).

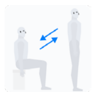
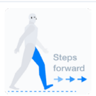
Recommendation:

- Measures of knee laxity/stability, and **knee joint range of motion;**
- Measures **lower-limb movement coordination;**
- Appropriate clinical or field tests that can identify a patient's baseline status relative to pain, function, and disability; and **detect side-to-side asymmetries;**
- Maximum voluntary isometric or isokinetic **quadriceps strength testing;**
- Use of the International Knee Documentation Committee 2000 Subjective Knee Evaluation Form (IKDC 2000) or Knee injury and Osteoarthritis Outcome Score (KOOS);
- The IKDC 2000 and KOOS include stairs, kneeling, squatting, **standing**, walking, running, and jumping.

Figure 2.3. *Summary and highlights from the best practice guideline for knee ligament sprain and knee meniscus and articular cartilage lesions.*

Table 2.1: *A list of MSK biomarkers referenced from the biomechanics research to describe the clinical relevance in diagnostic categories such as soft tissue or ligament injury, as well as the implications to the severity of injury, indication of recovery and a direct link from these signals to an individual's workability.*

FIGUR8 Biomarker	Diagnostic Category	Validated by Scientific Community			References
		Injury	Recovery	Workability	
Hip Range of Motion 	Soft tissue injury, ligament injury, fracture	Y	Y	Y	Hickey et al (2022)[11]
Knee Range of Motion 	Soft tissue injury, ligament injury, fracture	Y	Y	Y	van der Esch et. al (2006)[12] Reurink et al (2013)[13]

Muscle Function  	Soft tissue injury, ligament injury, fracture	Y	Y	Y	Giombini et al (2013) Neto et al (2015)[14,15]
Gait kinematics (e.g. stride time)  	Soft tissue injury, ligament injury, fracture	Y	Y	Y	Gopalswami et al (2021)[16]

Based on the literature survey and best practice guidelines, a list of knee specific biomarkers were selected as the output objectives during development of the FIGUR8 Knee bioMotion Assessment. Different placement options were tested to ensure data capture reliability and repeatability on diverse test subjects during dynamic activities in the four phases described below.

During bioMotion Assessment development, Phase 0 serves as the preliminary feasibility stage, where essential groundwork is laid to ensure the subsequent phases are viable and realistic. This phase involves any necessary testing to validate the feasibility of Phases 1 to 3, including protocol finalization, device placement testing, and algorithm development. Notably, data collected during Phase 0 is not incorporated into the validation dataset.

Phase 1 marks the initiation of internal testing, focusing on collecting and analyzing bioMotion Assessment data from a limited cohort of n=3 internal subjects.

In Phase 2, the testing scope expands with the introduction of the gold-standard, traditional biomechanics lab or the VICON motion capture system, alongside continued bioMotion Assessment data collection and analysis, still within the internal subject group.

Phase 3 represents a comprehensive internal and external testing phase. bioMotion Assessment data, VICON data, and electromyography (EMG) data are collected and analyzed across a broader demographic spectrum, encompassing various age groups, heights, and body mass indexes (BMI). Internal subjects undergo two visits each, with a cohort size of n=5, while an additional cohort of n=10 external subjects, each attending two visits, is introduced to enhance the dataset's diversity and robustness. Through these iterative phases, the FIGUR8 system undergoes rigorous evaluation and refinement, ultimately aiming for enhanced accuracy and applicability in real-world settings. After comparing all options and activity accuracy, a device placement guideline is drafted and finalized.

16 healthy individuals (F/M: 6/10, age: 37.1 ± 12.5 y, height: 69.0 ± 4.0 in, weight: 175.4 ± 30.2 lbs, bmi: 25.8 ± 3.4) were recruited to validate the normative range and reliability for FIGUR8's Knee bioMotion Assessment.

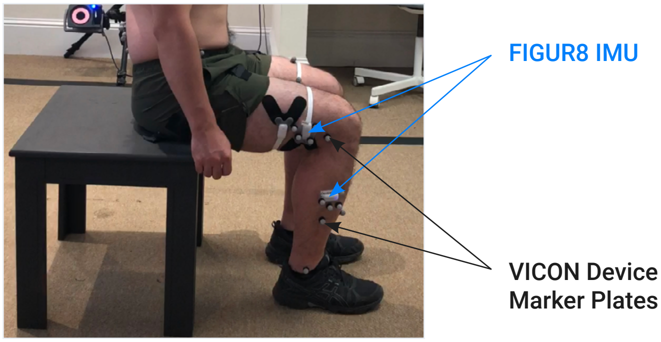


Figure 2.4. *The placement of FIGUR8's bMAP in conjunction with the VICON Device Plates during the validation phase.*

In the activity validation process, the objective is to develop protocols capable of minimizing dynamic angle discrepancies between FIGUR8's IMU and VICON's 3D motion capturing system, alongside validating the temporal accuracy of FIGUR8's surface mechanomyography (sMMG) and surface electromyography (EMG) measurements.

Joint motion is evaluated by comparing the technical fidelity and anatomical alignment of FIGUR8's data against a VICON MOCAP system via simultaneous collection while test subjects undergo a full FIGUR8 bioMotion Assessment.

Muscle function validation involves simultaneous collection of sMMG and EMG data, comparing results to ensure precise muscle contraction timing. Below is an example of a muscle contraction timing study with n=5 during the sit-to-stand-to-sit sequence. The average difference between EMG and sMMG contraction durations serves as a metric for comparing the two modalities.

Table 2.2: *(Left) Sit to Stand to Sit Contraction Timing Validation Data. (Right) sMMG and EMG raw signal comparison during the same activity. Contraction duration is computed as the difference between deactivation time (indicated in red) and activation time (highlighted in green), as recorded by the EMG and sMMG devices. Statistical significance is assessed using a T test to derive the p-value as comparable methods to determine muscle contraction timing.*

Muscle Contraction Timing Validation (n=5)		
Hamstring	L	R
Average Difference	-0.077 s	-0.060 s
T Test	p = 0.637	p = 0.803

A comprehensive analysis based on the methodologies described above was conducted to iterate the bioMotion Assessment and phases to determine which evaluations to include in the assessment and sensor placement design. This was completed after confirming acceptable dynamic joint angle measurement accuracy, muscle contraction timing measurement accuracy, as well as reliability between muscle volumetric contraction measurement and dynamic angle reliability measurements. Details are listed in Table 2.3.

Table 2.3: *A comprehensive list of the accuracy and inter- / intra- assessment variability of FIGUR8's Knee Assessment Protocol.*

Assessment	Muscle CT* Accuracy	Muscle VCM** Reliability	Angle Accuracy	Angle Reliability
Knee	p=0.637 - 0.900	± 2.64 - 4.66mm	2.79° - 8.09°	± 4.62° - 10.54°
*Contraction Timing **Volumetric Contraction Measurement				

Dynamic Joint Angles Measurement Accuracy

Activity	Hip		Knee	
	Avg abs error	**RMSE**	**Avg abs error**	**RMSE**
R Active Seated Knee Extension	n/a	n/a	2.94 ± 3.39	4.47
L Active Seated Knee Extension	n/a	n/a	3.59 ± 2.27	4.24
R Active Seated Hip & Knee Flexion	8.05 ± 5.57	9.77	14.6 ± 4.87	15.38
L Active Seated Hip & Knee Flexion	8.48 ± 4.55	9.61	13.17 ± 6.70	14.75
Sit to Stand to Sit (L Hip Flexion)	5.00 ± 3.52	6.11	n/a	n/a
Sit to Stand to Sit (L Knee Extension)	n/a	n/a	1.02 ± 0.78	1.28
Sit to Stand to Sit (R Hip Flexion)	5.29 ± 4.22	6.75	n/a	n/a
Sit to Stand to Sit (R Knee Extension)	n/a	n/a	0.67 ± 0.61	0.91

Muscle Contraction Timing Measurement Accuracy

Activity	Muscle	N	Left Limb	Right Limb
Right Limb	Quadricep	L: n=4; R: n=8	p = 0.862	p = 0.737
	Hamstring	L: n=5; R: n=5	p = 0.637	p = 0.803
Straight Leg Raise	Quadricep	L: n=4; R: n=8	p = 0.900	p = 0.828

Dynamic Joint Measurement Reliability: INTRA/INTER Assessment Variability

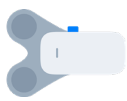
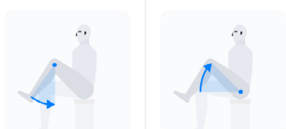
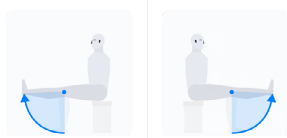
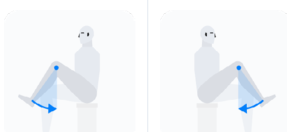
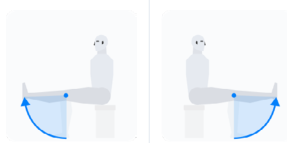
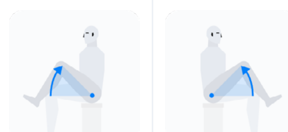
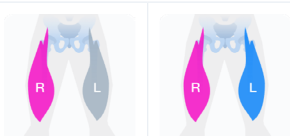
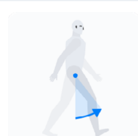
Activity	INTRA - Assessment Variability n=15x2		INTER - Assessment Variability n=15x2	
	Hip (deg)	**Knee (deg)**	**Hip (deg)**	**Knee (deg)**
R Active Seated Knee Extension		± 4.86		± 7.08
L Active Seated Knee Extension		± 3.32		± 4.62
R Active Seated Hip & Knee Flexion	± 2.85	± 4.11	± 7.85	± 9.55
L Active Seated Hip and & Flexion	± 2.43	± 4.43	± 8.07	± 10.54
Gait (Flexion) L; R	± 3.15; ± 3.53		± 4.68; ± 4.97	
Gait (Extension) L; R	± 3.46; ± 3.18		± 4.69; ± 5.04	

Muscle Volumetric Contraction Measurement Reliability: INTRA/INTER Assessment Variability

Activity	INTRA - Assessment Variability n=15x2			
	Left Quad	**Right Quad**	**Left Ham**	**Right Ham**
Sit to Stand to Sit	± 1.76 mm	± 1.92 mm	± 1.28 mm	± 1.28 mm
Straight Leg Raise	± 1.58 mm	± 1.40 mm		
	INTER - Assessment Variability n=15x2			
	Left Quad	**Right Quad**	**Left Ham**	**Right Ham**
Sit to Stand to Sit	± 4.74 mm	± 3.77 mm	± 4.30 mm	± 4.66 mm
Straight Leg Raise	± 2.64 mm	± 3.32 mm		

After the placement and the activities are finalized from the validation and verification process, FIGUR8 bioMotion Assessment protocols are converted into an iOS app, where the placement and activities are set to create the most efficient software programs to collect lab-grade biomechanics data with FIGUR8's portable bMAP system. The design of FIGUR8 bioMotion Assessments has three components: (a) Device placement, (b) Activities protocol and (c) Biomarker Metrics.

Table 2.4: *The overview of the Knee Assessment.*

(a) Device Placements			
7 Device Placements			
	1. Pelvis 2. R Lower Leg 3. L Lower Leg		
	4. R Quadriceps 5. L Quadriceps 6. R Hamstrings 7. L Hamstrings		
(b) Activities from the Knee Assessment			
Active Seated Hip & Knee Flexion	Active Knee Extension	Straight Leg Raise	Sit-to-Stand-to-Sit, Gait
			
(c) Biomarker Metrics			
Range of Motion	Knee Flexion	Knee Extension	Hip Flexion
			
Muscle Function	Quad output & Symmetry (Straight Leg Raise)	Quad output & Symmetry (Sit-to-stand-to-sit)	Ham output & Symmetry (Sit-to-stand-to-sit)
			
Functional Activity	Stride Timing during Gait	Sagittal Hip Motion during Gait	
			

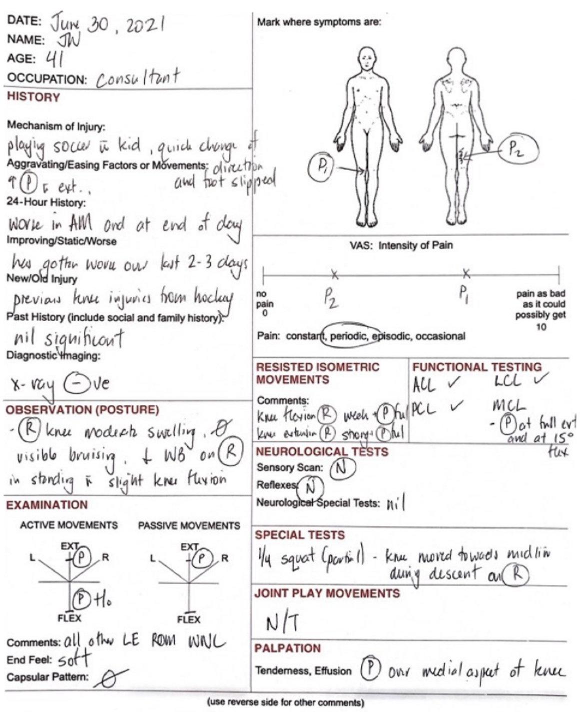
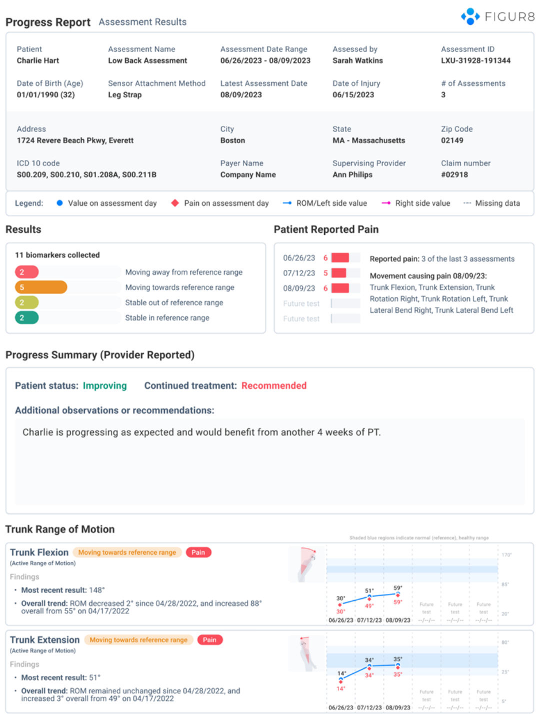
Results

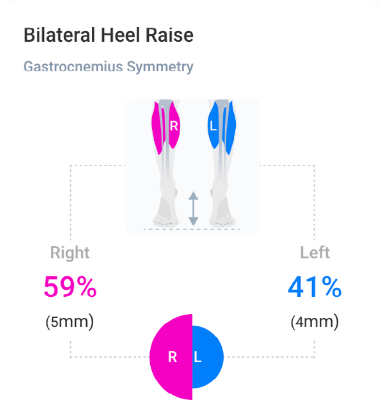
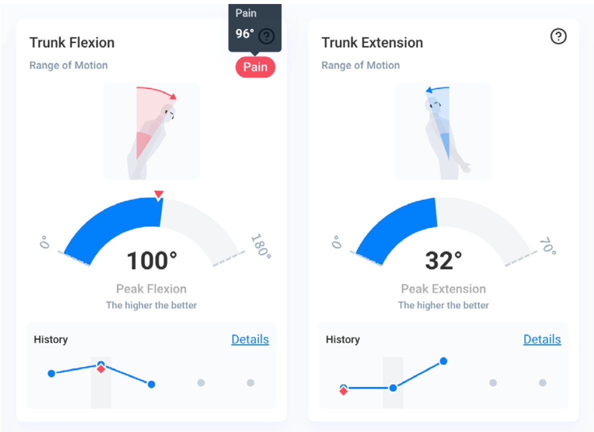
3. Precision powering progress:
How clinicians use FIGUR8 bioMotion data to guide clinical decision making

The significant benefits of an experienced clinician, with their knack for diagnosing complex issues through seasoned insight and intuition, are well recognized. A human brain has the capacity to sift through millions of data points, drawing on past experiences and intuitive understanding to reach conclusions. FIGUR8's bMAP covers major categories of testing in evaluating musculoskeletal health with additional digital information to augment decision making for clinicians, empowering them with data that validates care, supports care and drives better outcomes.

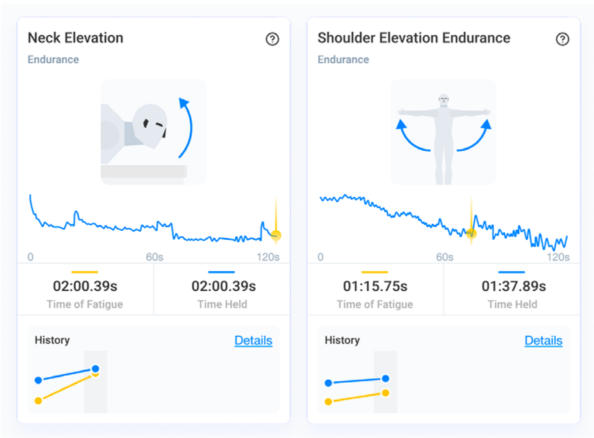
Table 3.1 compares general reporting from the traditional MSK assessment to FIGUR8's bioMotion Assessment-based reports and showcases example categories of testing.

Table 3.1: *A comparison between traditional MSK assessment reporting and FIGUR8's bioMotion Assessment and bioMotion data reporting. Each bioMotion Assessment captures data that enhances traditional testing and evaluation with additional data from each biomarker category.*

<table>
<tr><th>Traditional MSK Assessment:
Subjective, Varied Observations</th><th>FIGUR8 bioMotion Report:
Objective, Data-Driven Observations</th></tr>
<tr><td>
DATE: June 30, 2021
NAME: JW
AGE: 41
OCCUPATION: Consultant
HISTORY
Mechanism of Injury: playing soccer c̄ kid, quick change of direction and foot slipped
Aggravating/Easing Factors or Movements: ↑ P c̄ ext.
24-Hour History: worse in AM and at end of day
Improving/Static/Worse: has gotten worse over last 2-3 days
New/Old Injury: previous knee injuries from hockey
Past History (include social and family history): nil significant
Diagnostic Imaging: x-ray (–)ve
OBSERVATION (POSTURE): - (R) knee moderate swelling, Ø visible bruising, ↓ WB on (R) in standing c̄ slight knee flexion
EXAMINATION
ACTIVE MOVEMENTS: EXT (P), L, R, (P) 110, FLEX
PASSIVE MOVEMENTS: EXT (P), L, R, FLEX
Comments: all other LE ROM WNL
End Feel: soft
Capsular Pattern: Ø
Mark where symptoms are: P1, P2
VAS: Intensity of Pain
no pain 0 — P2 — P1 — pain as bad as it could possibly get 10
Pain: constant, periodic, episodic, occasional
RESISTED ISOMETRIC MOVEMENTS
Comments: Knee flexion (R) weak + (P) full; knee extension (R) strong + (P) full
FUNCTIONAL TESTING: ACL ✓ LCL ✓ PCL ✓ MCL - (P) at full ext and at 15° flex
NEUROLOGICAL TESTS
Sensory Scan: (N)
Reflexes: (N)
Neurological Special Tests: nil
SPECIAL TESTS: 1/4 squat (partial) - knee moved towards midline during descent on (R)
JOINT PLAY MOVEMENTS: N/T
PALPATION
Tenderness, Effusion: (P) over medial aspect of knee
(use reverse side for other comments)</td>
<td>
Progress Report Assessment Results — FIGUR8
Patient: Charlie Hart | Assessment Name: Low Back Assessment | Assessment Date Range: 06/26/2023 - 08/09/2023 | Assessed by: Sarah Watkins | Assessment ID: LXU-31928-191344
Date of Birth (Age): 01/01/1990 (32) | Sensor Attachment Method: Leg Strap | Latest Assessment Date: 08/09/2023 | Date of Injury: 06/15/2023 | # of Assessments: 3
Address: 1724 Revere Beach Pkwy, Everett | City: Boston | State: MA - Massachusetts | Zip Code: 02149
ICD 10 code: S00.209, S00.210, S01.208A, S00.211B | Payer Name: Company Name | Supervising Provider: Ann Philips | Claim number: #02918
Legend: Value on assessment day; Pain on assessment day; ROM/Left side value; Right side value; Missing data
Results
11 biomarkers collected
2 Moving away from reference range
5 Moving towards reference range
2 Stable out of reference range
2 Stable in reference range
Patient Reported Pain
06/26/23 6
07/12/23 5
08/09/23 6
Future test
Future test
Reported pain: 3 of the last 3 assessments
Movement causing pain 08/09/23: Trunk Flexion, Trunk Extension, Trunk Rotation Right, Trunk Rotation Left, Trunk Lateral Bend Right, Trunk Lateral Bend Left
Progress Summary (Provider Reported)
Patient status: Improving Continued treatment: Recommended
Additional observations or recommendations:
Charlie is progressing as expected and would benefit from another 4 weeks of PT.
Trunk Range of Motion
Shaded blue regions indicate normal (reference), healthy range
Trunk Flexion — Moving towards reference range — Pain
(Active Range of Motion)
Findings
• Most recent result: 148°
• Overall trend: ROM decreased 2° since 04/28/2022, and increased 88° overall from 55° on 04/17/2022
170° 85° 20°; 30° 51° 59°; 30° 49° 59°; 06/26/23 07/12/23 08/09/23; Future test --/--/-- Future test --/--/-- Future test --/--/--
Trunk Extension — Moving towards reference range — Pain
(Active Range of Motion)
Findings
• Most recent result: 51°
• Overall trend: ROM remained unchanged since 04/28/2022, and increased 3° overall from 49° on 04/17/2022
80° 25° 5°; 14° 34° 35°; 14° 34° 35°; 06/26/23 07/12/23 08/09/23; Future test --/--/-- Future test --/--/-- Future test --/--/--</td></tr>
<tr><td></td><td>Summary of Single Assessment, Longitudinal and Reference Biomechanics Data is combined to give true insight into progress and recovery</td></tr>
</table>

<table>
<tr><th colspan="2">Example Categories of Testing</th></tr>
<tr><td>Manual Muscle Testing
Initial assessment: 3/5</td><td>Muscle function side-by-side comparison

</td></tr>
<tr><td>ROM Assessment:
Limited ROM on the trunk extension.</td><td>Dynamic Motion Assessment:
Precise range of motion measurement with clear indicator of patient reported pain, where and when it occurs.

</td></tr>
<tr><td>Functional Endurance test

Head Elevation Endurance:
2 minutes. Satisfactory

Shoulder Elevation Endurance:
1:37 minutes. Limited Endurance.</td><td>Endurance testing with stability metrics and algorithms to identify fatigue points.

</td></tr>
</table>

Additional layer of specificity in bioMotion data for clinical deepdive of individual biomarkers

bioMotion data collected during a FIGUR8 bioMotion Assessment are summarized as simple biomarkers to allow longitudinal tracking and reporting in a summary view. An additional layer of specificity is provided in the clinician-facing Web Portal, where a detailed biosignal view of a patient's movement: the quality, timing, duration and consistency of joint motion and muscle function is accessible. This data has historically only been available through qualitative and subjective movement analysis and now providers have quantitative data available to them to support their evaluation and treatment recommendations.

The following two examples highlight the value of additional biometric signals FIGUR8's bMAP can capture and visualize. Figure 3.1 showcases the before and after treatment of a patient's gastrocnemius muscle function, both in symmetry and in the ability to activate and sustain the muscle contraction.

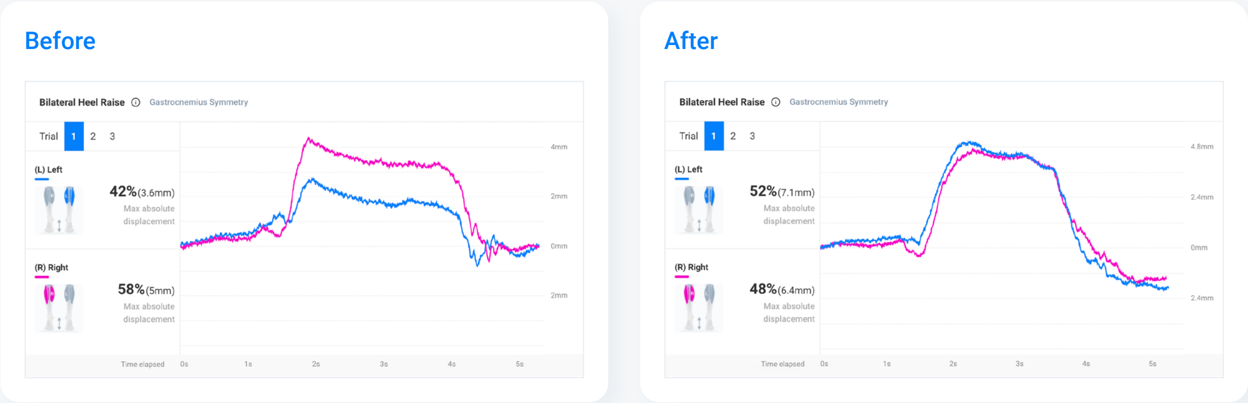


Figure 3.1. *(Left) Bilateral heel raise muscle symmetry plot of a back injury patient before physical therapy. A clear asymmetry of muscle function was detected, as well as the inability to sustain contraction during the heel raise motion. (Right) After 3 months of physical therapy, satisfactory symmetry and smooth control of muscle activation were shown in the data.*

Additionally, FIGUR8 Enabled clinicians are able to capture movement stability during functional endurance activities through the bMAP. Traditionally, these activities are captured with a stopwatch focusing purely on the length of time an individual is able to hold a position with very little insight into the compensations and/or quality with which they use to perform the task. With the addition of FIGUR8 bioMotion data, the quality and coordination of the motion is evident in the data and can be compared over time to see evidence of improvement, see Figure 3.2 below for a comparison of quality of motion and coordination before and after treatment.

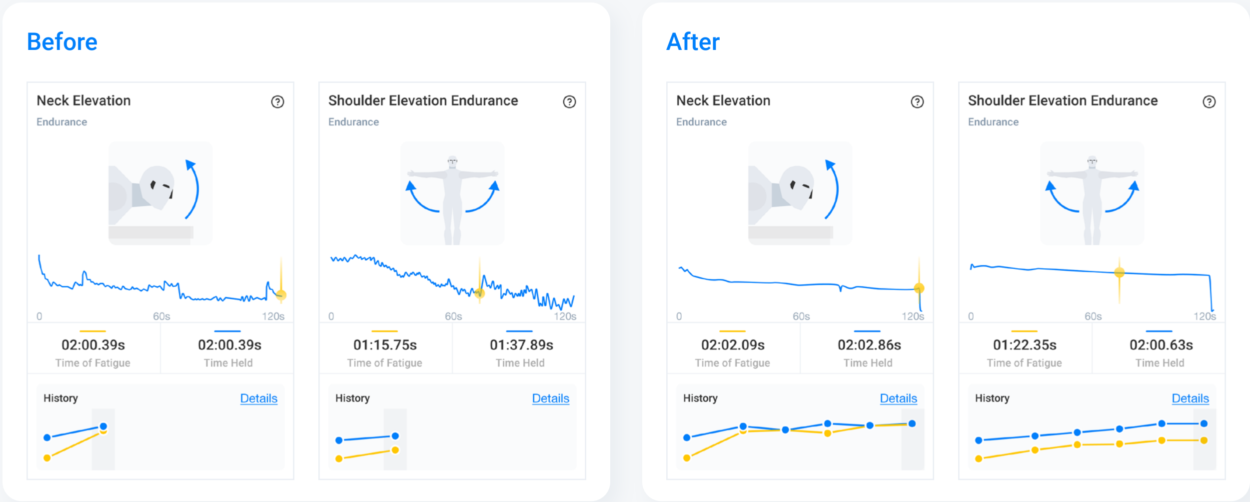


Figure 3.2. *bioMotion data of a head elevation endurance and shoulder elevation endurance assessment, comparing before and after physical therapy for a shoulder injury. The stability improvement was clear from the biosignal captured by the bMAP.*

Additionally, FIGUR8 Enabled clinicians are able to capture movement stability during functional endurance activities through the bMAP. Traditionally, these activities are captured with a stopwatch focusing purely on the length of time an individual is able to hold a position with very little insight into the compensations and/or quality with which they use to perform the task. With the addition of FIGUR8 bioMotion data, the quality and coordination of the motion is evident in the data and can be compared over time to see evidence of improvement, see Figure 3.2 below for a comparison of quality of motion and coordination before and after treatment.

Population health insights, through modernizing musculoskeletal data capture

The advent of digital technology equips us with tools to consolidate data and insights, making it possible to share aggregated recovery experiences and optimal treatment outcomes in formats that are conducive to input into machine learning and artificial intelligence systems. FIGUR8's bioMotion data enables the comparison of an individual patient's journey with that of others in real-time. This capability means we can effectively understand the MSK health of an individual by gauging injury severity, monitoring recovery progress, and evaluating the extent of recovery all in order to achieve the highest level of medical improvement, from a population health perspective.

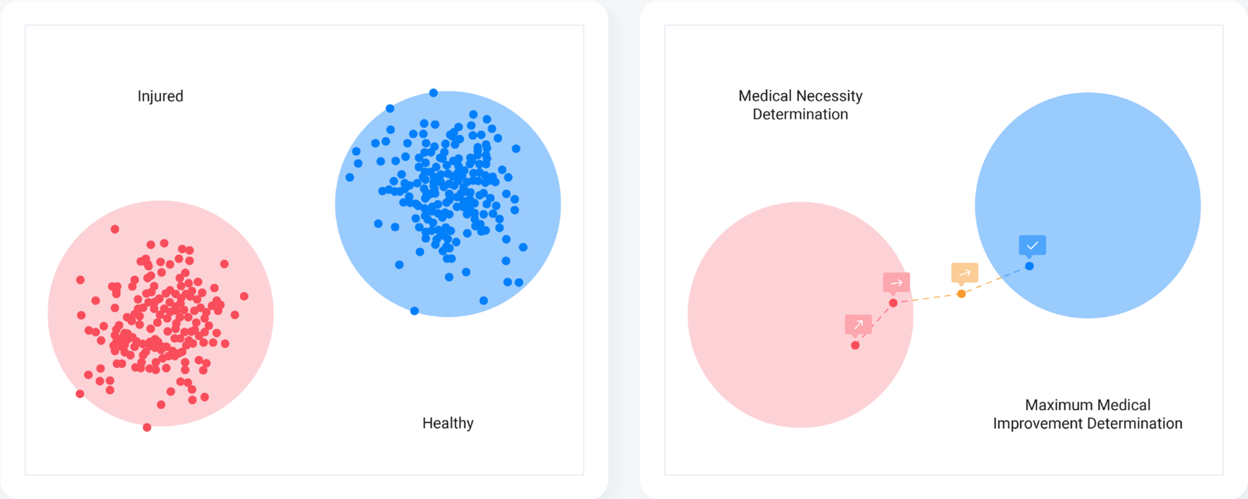


Figure 3.3. *(Left) Digital information enables the ability to define the cluster of data between injured and healthy. (Right) The cluster allows FIGUR8 Enabled clinicians to compare each report output from a single patient with group demographic data and make critical decisions such as medical necessity or maximum medical improvement.*

Rich MSK data provided by FIGUR8's bioMotion platform allows us to utilize modern statistical and machine learning methods that can separate injuries by severity and distinct types effectively. The algorithm behind the analysis operates within a high-dimensional linear vector space of biomarkers, effectively navigating this complex landscape through the application of nonlinear transformations. By converting the vast data into a more manageable subspace, FIGUR8 translates the pool of data points into a representation that enhances the separation of clusters, which are inherent in the original linear space as demonstrated in Figure 3.3. The rich multivariate data needed to apply these machine learning techniques are pulled from the multi-modal, multi-sensor, on body data that the FIGUR8 bioMotion Assessments collects simultaneously. This is unlike traditional methods of MSK health assessment, where typically only one or two biomarkers can be collected and then compared for the same activities.

Advanced clustering algorithms allow collections of biomarkers to be analyzed in concert, considering dozens or even hundreds at a time, to identify similar properties across these extensive datasets. These clusters then represent similar groups, or subsets, of biomarker values, corresponding to different patient conditions and specific ICD-10 codes. Through this sophisticated analysis, clusters can be created specific to injury types and recovery trajectories with unprecedented precision, shedding light on subtle distinctions that might be overlooked in less comprehensive evaluations.

With the bMAP, FIGUR8 Enabled clinicians are empowered with a novel data set that can drive advanced analysis of entire populations, while gaining clarity on trajectory of recovery for individual patients.

From complexity to clarity:
Leveraging bioMotion data to understand MSK health status

Recovery from MSK conditions is multi-faceted, involving numerous biomarkers that can indicate change in MSK health due to the interconnected nature of the MSK system. FIGUR8 has developed a holistic approach, tracking progress through trends in biomarker metrics relative to reference ranges measured on healthy active individuals. Each bioMotion Assessment captures critical biomarkers indicative of recovery, alongside definitions of health derived from our data collection and literature reviews. This methodology enables FIGUR8 Enabled clinicians to access a concise overview of essential biomarkers that have achieved stability for each individual patient. Signs of "healthy" fall into two categories: within range and outside of range. Biomarkers that are within range have consistently fallen within the reference range over the last three bioMotion Assessments, indicating stable recovery within normal health parameters. Outside of range signifies biomarkers that have held stable over the last three bioMotion Assessments, yet remain outside the normal range.

Figure 3.4. *An example bioMotion data visualization used in FIGUR8 bioMotion Analysis Reporting.*

This distinction recognizes patients who have reached a stable point in their recovery but cannot achieve the standard healthy range, likely due to pre-existing conditions or patient outlier metrics. In illustrating recovery patterns, it becomes easy to identify trends of regression, progression, and stabilization. Additionally, during a FIGUR8 bioMotion Assessment patient-reported pain is monitored and documented, specifically recording pain associated with dynamic movements. This information on activity-specific pain is crucial for clinicians to investigate unresolved issues and pinpoint areas of concern. Furthermore, an in-depth summary of each biomarker category is provided, offering insights into longitudinal data, progress tracking, and comparisons with normative data, facilitating a comprehensive understanding of the patient's recovery trajectory, see Figure 3.4.

Demonstrated value of FIGUR8 through expedited recovery

FIGUR8 demonstrates value through expedited recovery by providing clinicians with precise, objective data that allows for tailored treatment plans and interventions. By leveraging advanced biomechanical insights, FIGUR8 enables clinicians to identify areas of weakness or imbalance early on, leading to targeted interventions that accelerate the recovery process. With real-time feedback and personalized guidance, patients can optimize their rehabilitation efforts, leading to faster recovery times and improved outcomes as shown in Figure 3.5 below. This proactive approach not only reduces the duration of recovery but also minimizes the risk of setbacks or complications, ultimately delivering enhanced value to both patients and healthcare providers.

FIGUR8 enabled clinicians deliver effective care that exceeds national standards

Diagnostic Group:
M54.12 — Cervical Radiculopathy

- Common in heavy labourers and workers that use vibrating machinery in their job
- Presents as pain that radiates from the neck to the arm, shoulder, elbow, wrist and/or hand; weakness and uncoordinated movements occur in more severe cases
- Most cases resolve with conservative treatment and do not require surgery

ODG Guidelines for Cervical Radiculopathy

- Average Claim Duration: 73 days
- Average Claim Cost: $19,169

FIGUR8 enabled clinicians delivering care for Cervical Radiculopathy

- Average Time to Stability: 57 days
- Potential Cost Savings: **$4,204**

Figure 3.5. *A condition specific group demonstrates a 22% reduction in time to MSK health plateau for injured workers being treated by FIGUR8 enabled clinicians from September 2022 to February 2024.*

Conclusion

FIGUR8's bioMotion Assessment Platform represents a groundbreaking advancement in the field of musculoskeletal care. By leveraging cutting-edge technology and biomechanical insights, FIGUR8 empowers clinicians with precise, objective data to inform diagnosis, treatment, and rehabilitation strategies. With a focus on personalized care and improved patient outcomes, FIGUR8 is revolutionizing the way musculoskeletal conditions are understood and managed.

As the healthcare landscape continues to evolve, the demand for innovative solutions that prioritize precision and efficiency has never been greater. FIGUR8 stands at the forefront of this movement, offering clinicians a powerful tool to optimize their practice and deliver exceptional care to every patient.

As we look to the future, FIGUR8 remains committed to driving advancements in musculoskeletal care, forging new paths towards improved outcomes, enhanced patient experiences, and ultimately, a healthier, more mobile world.

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FIGUR8