

Automated Evaluation of Physical Therapy Exercises by Multi-Template Dynamic Time Warping of Wearable Sensor Signals



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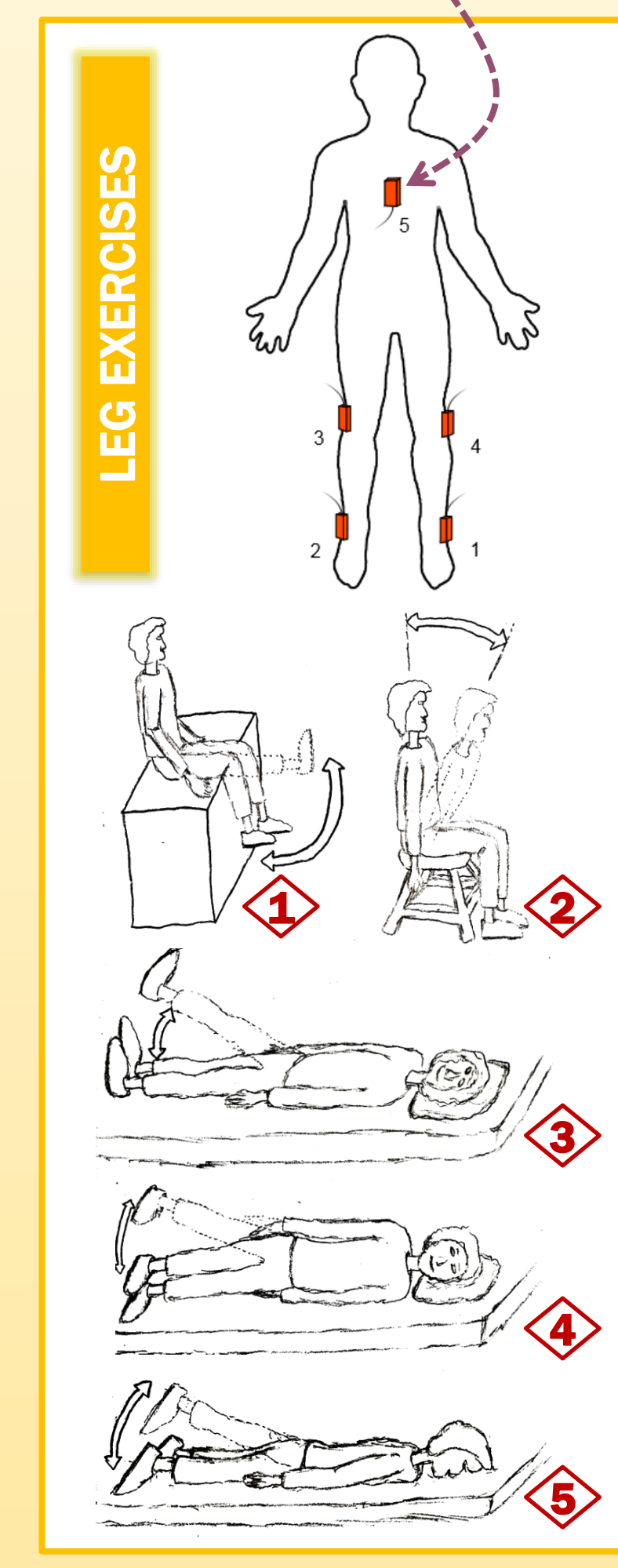
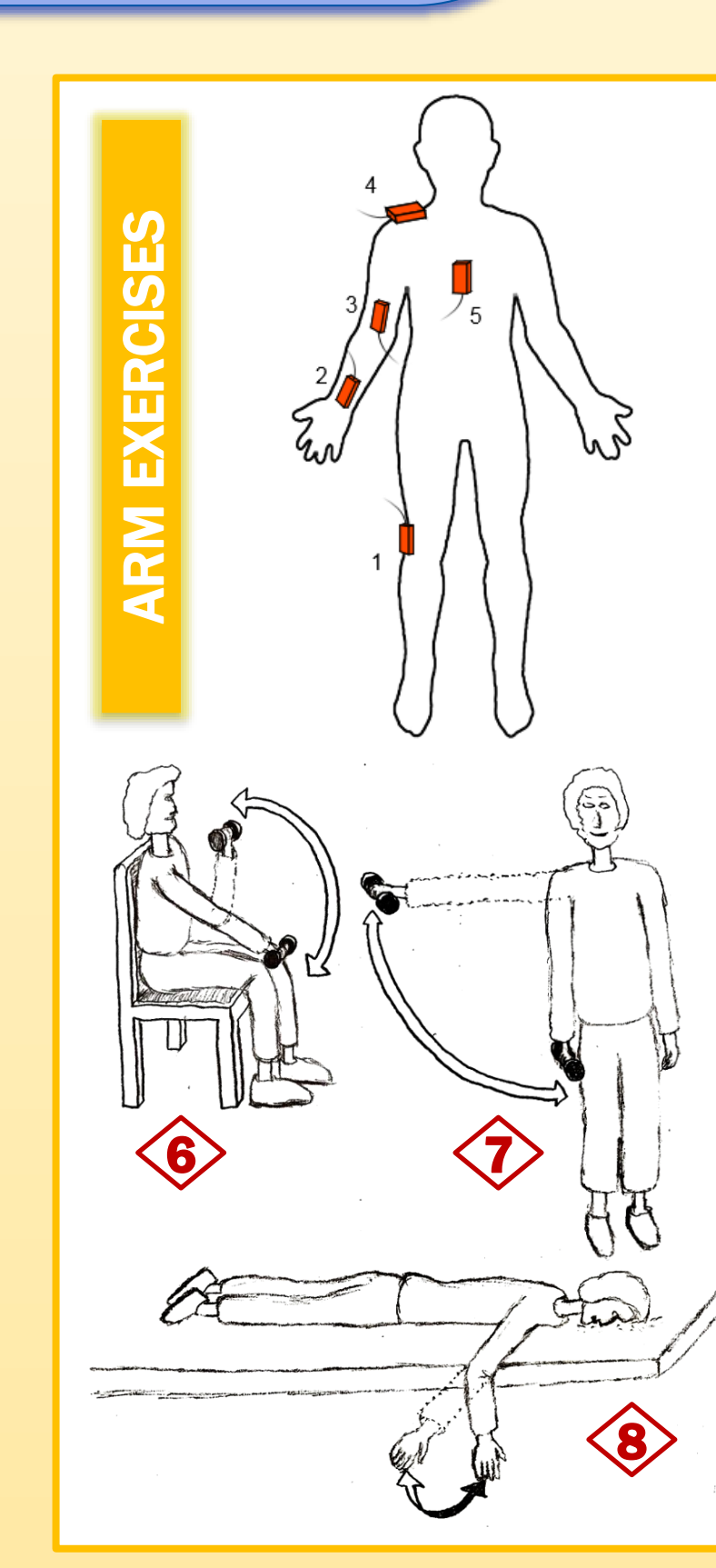
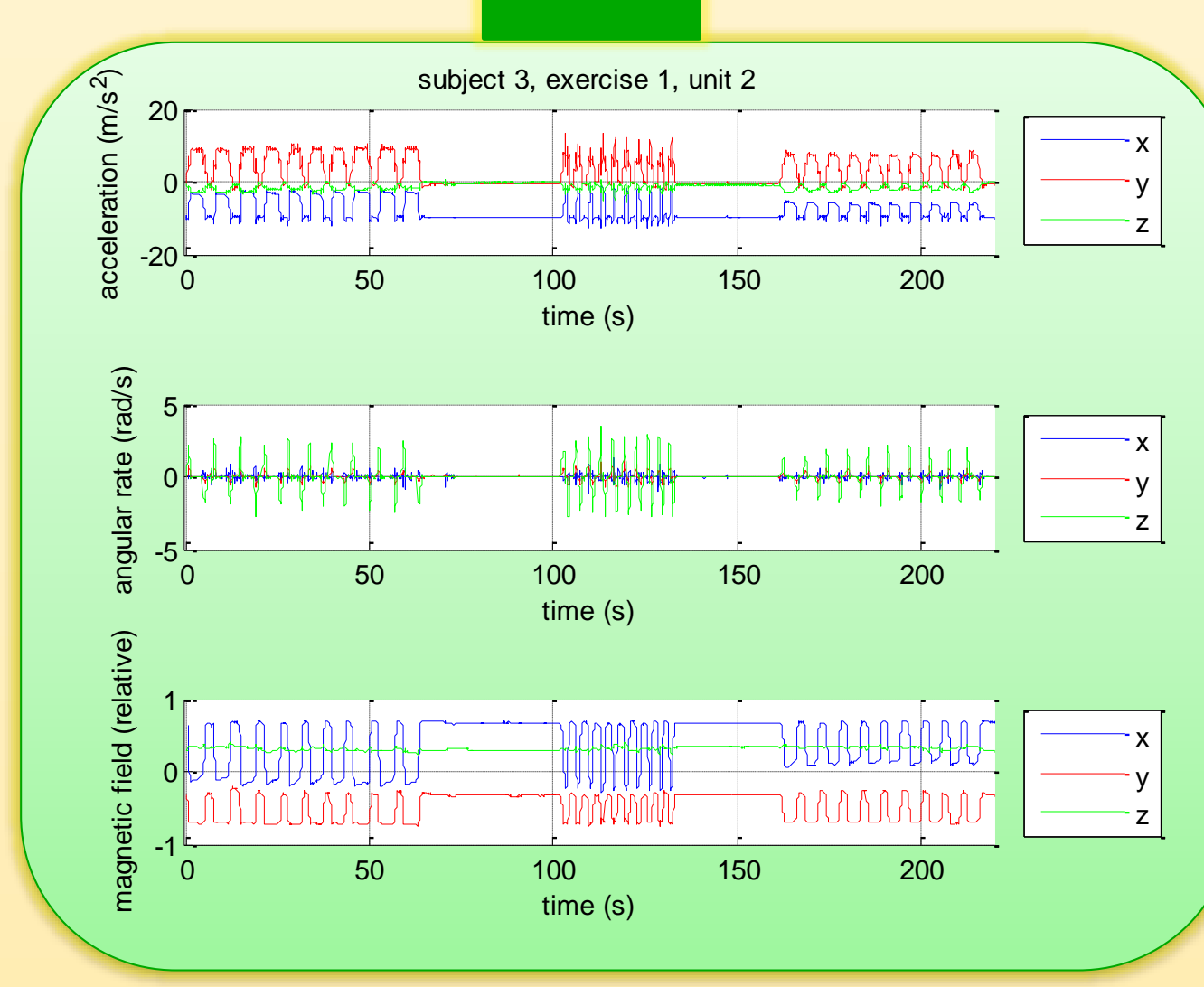
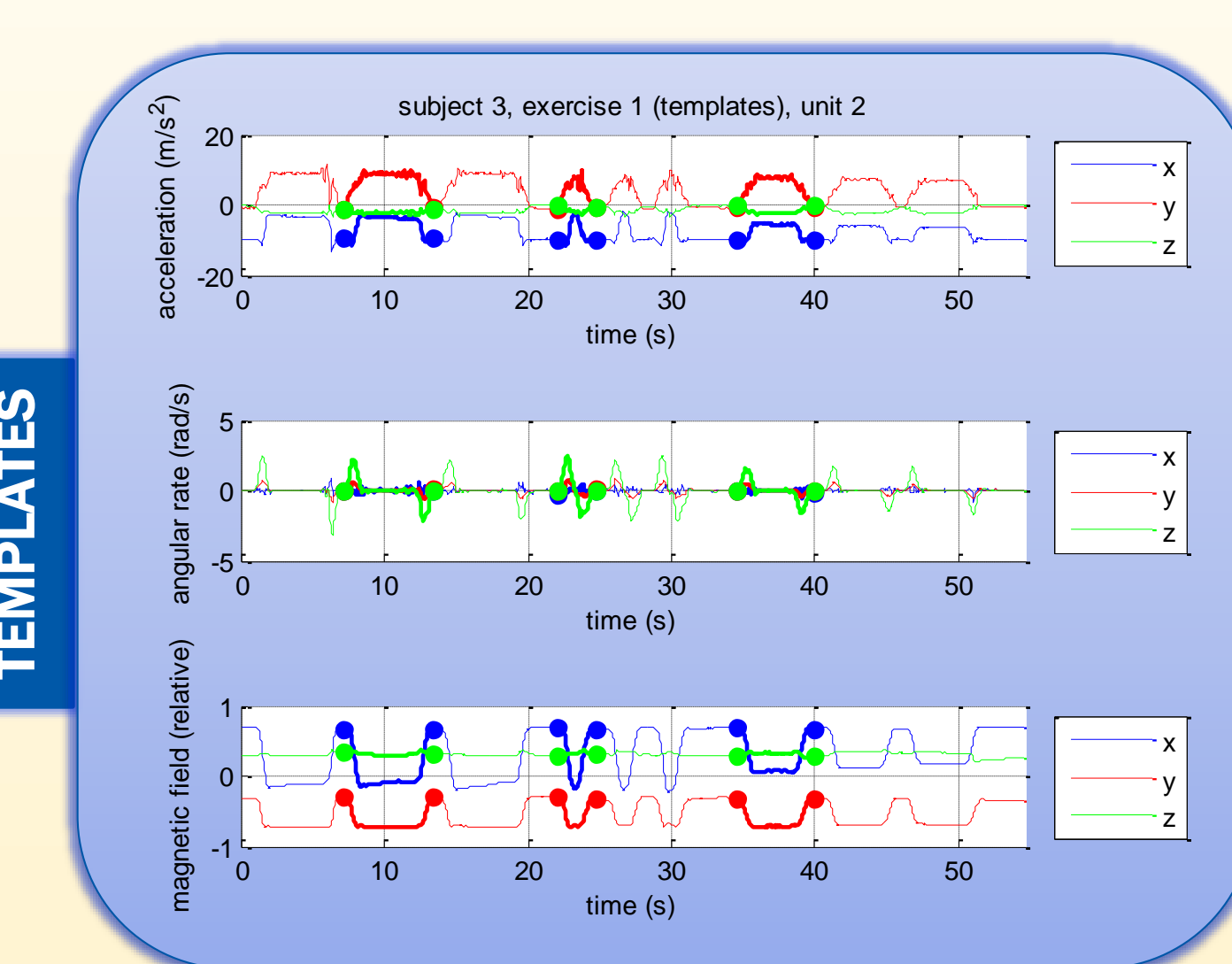
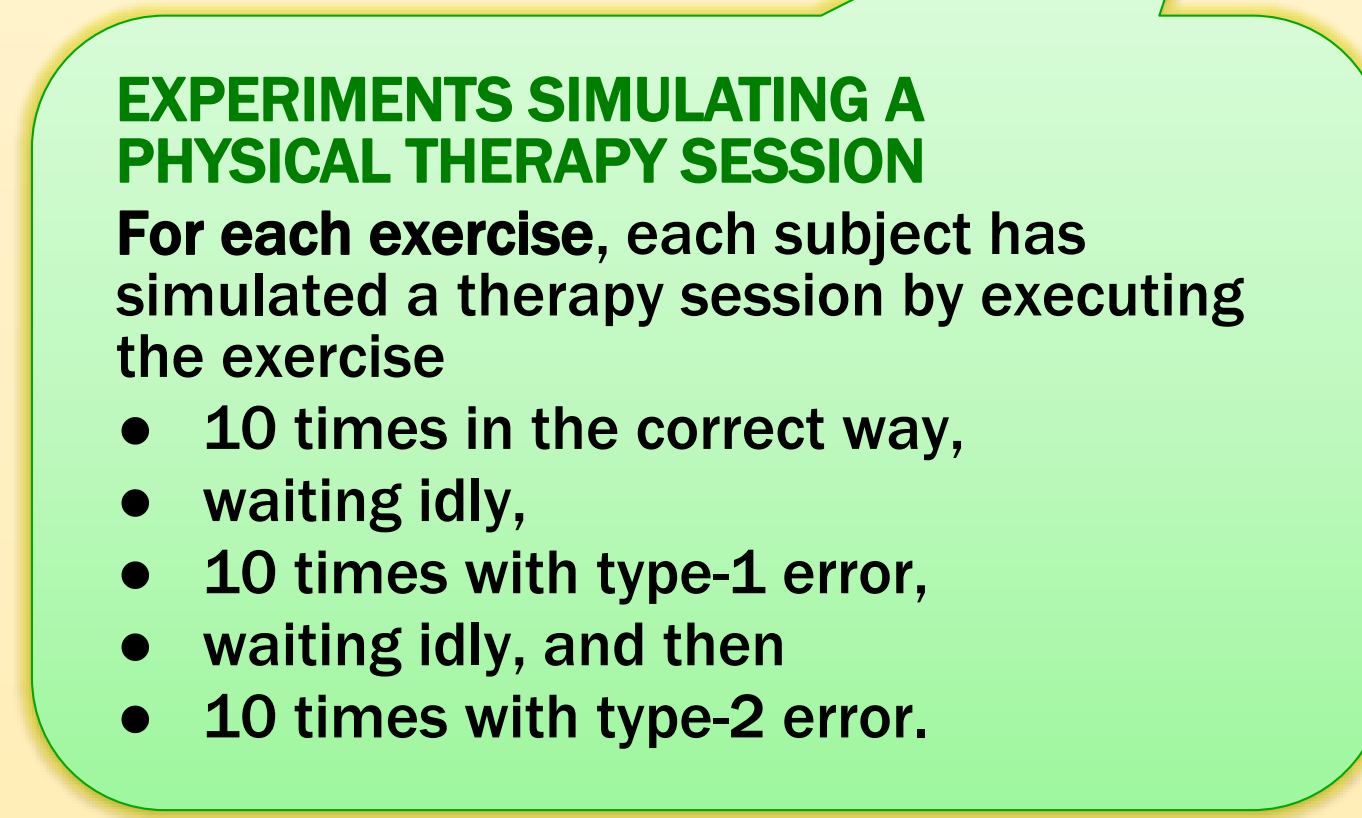
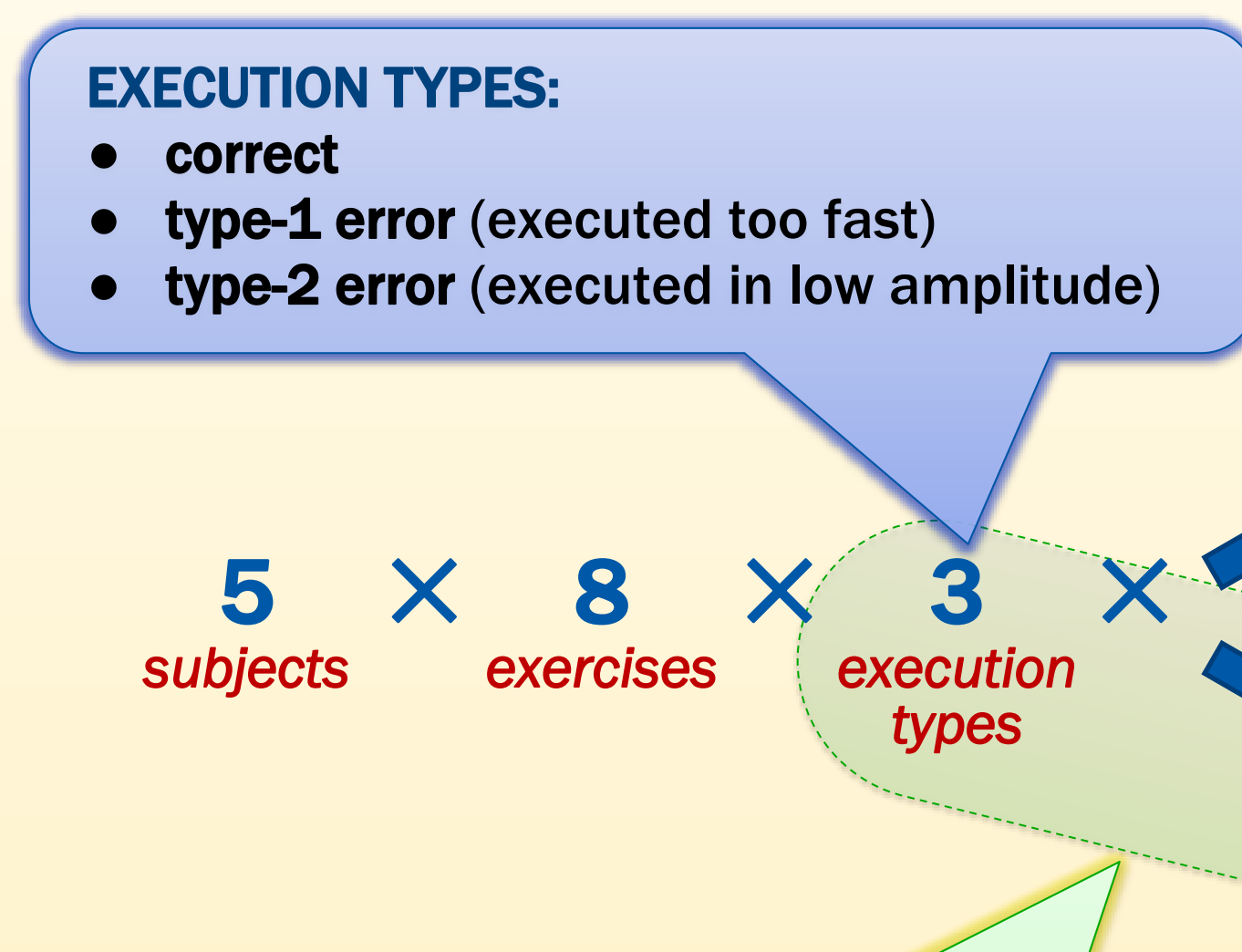
Introduction

- Physical therapy often requires repeating certain exercise movements.
- Patients first perform the required exercises under supervision in a hospital or rehabilitation center.
→ **PARTIAL AND SUBJECTIVE FEEDBACK**
- Most patients continue their exercises at home.
→ **NO FEEDBACK**
- The intensity of a physical therapy session is estimated by the number of correct executions.

OBJECTIVE : to detect and evaluate all exercise executions in a physical therapy session by using wearable motion sensors based on template recordings

Dataset

- 5 wearable motion sensors, each containing a tri-axial accelerometer, gyroscope, and magnetometer
- 8 exercise types performed by 5 subjects
- Each exercise is assumed to have 3 execution types: one correct and two erroneous (fast and low-amplitude execution)
- one template for each execution type of each exercise of each subject
→ **120 TEMPLATES IN TOTAL**
- To simulate a physical therapy session, for each exercise, each subject performs the exercise 10 times in the correct way, then 10 times with type-1 error, and finally 10 times with type-2 error. Between these 3 blocks, the subject is idle. → **1,200 TEST EXECUTIONS IN TOTAL**



Algorithm

- Standard DTW**
 - measures the similarity between two signals that are different in time or speed
 - matches two signals by transforming their time axes nonlinearly to maximize the similarity
- Multi-Template Multi-Match DTW (MTMM-DTW)** has been developed based on DTW to
 - detect multiple occurrences of multiple template signals in a long test signal
 - both detect and classify the occurrences

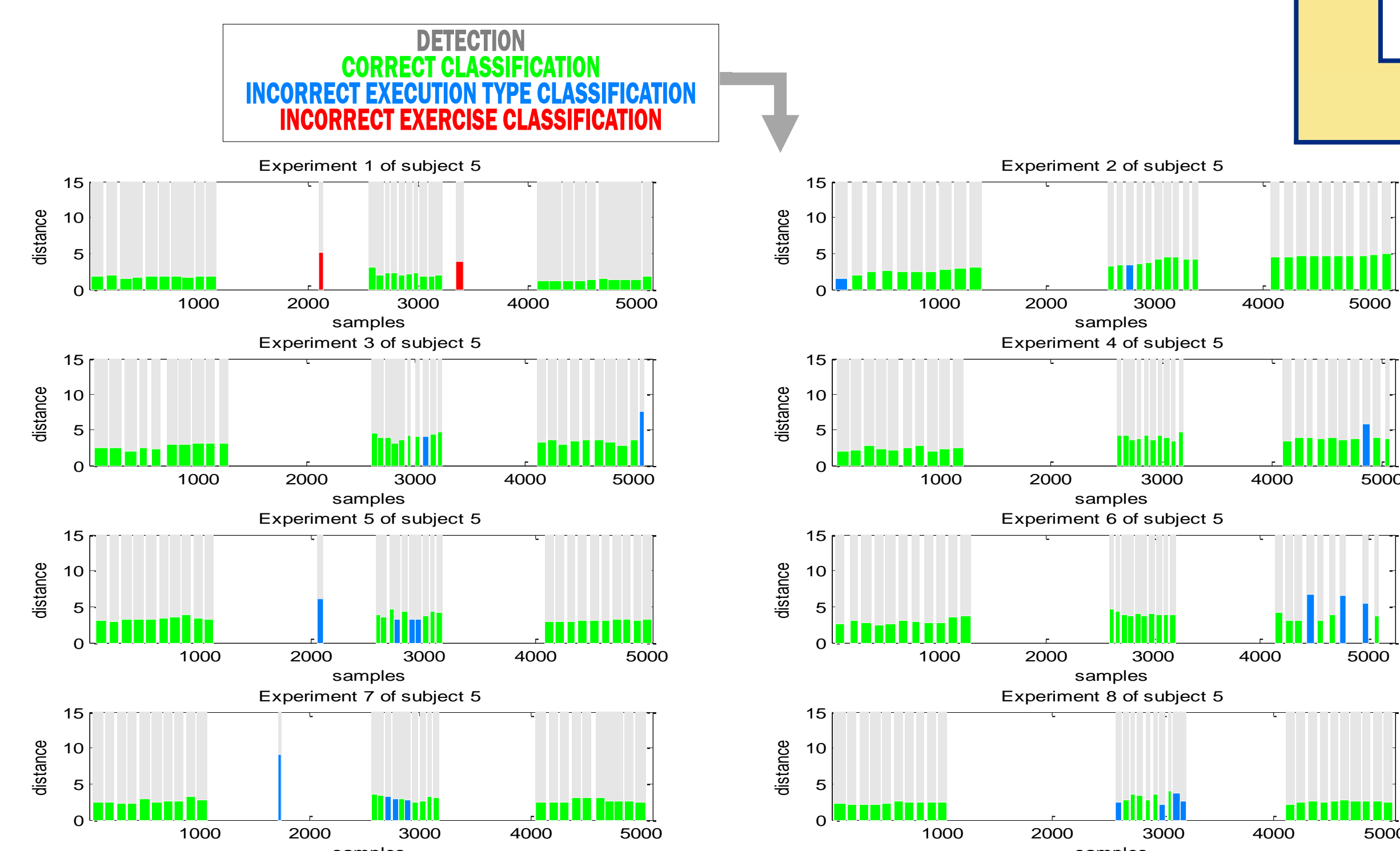
Features of MTMM-DTW:

- The number of templates, occurrences, their positions, and lengths of the template and test signals may be arbitrary.
- The signals may be multi-D.
- A threshold factor can be selected to prevent relatively short matches compared to the matching template.
- The amount of overlap between the matched subsequences can be adjusted.
- Any modification to the DTW algorithm may be used in MTMM-DTW.

Experimental Results

- We apply the proposed MTMM-DTW algorithm to each test signal with the 24 template signals of the same subject for 8 exercise types × 3 execution types.
- Each detected exercise must be at least half the length of the matching template.
- Detections with a normalized DTW distance larger than 10 are omitted.

Number of total executions	1,200
Number of executions detected	1,125
Accuracy of exercise classification	93.5%
Accuracy of exercise and execution type classification	88.7%
Misdetection rate (MDs / positives)	8.6%
False alarm rate (FAs / negatives)	4.9%
Sensitivity	91.4%
Specificity	95.1%



Conclusion

- The proposed system can be used in tele-rehabilitation to provide feedback to the patient exercising remotely and assessing the effectiveness of the exercising session.
- In previous systems, each execution is recorded separately or cropped manually.
- Our system
 - automatically detects the individual executions and idle time periods,
 - classifies each execution as one of the exercise types,
 - evaluates its correctness, and
 - identifies the error type if any.

References

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- P. Tormene, T. Giorgino, S. Quaglini, and M. Stefanelli, "Matching incomplete time series with dynamic time warping: an algorithm and an application to post-stroke rehabilitation," *Artif. Intell. Med.*, 45(1):11-34, Jan. 2009.