POF Sensor for Dynamic Physiological Evaluation in a Dog-Assisted ASD Therapy: A Case Study

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Abstract. Optical fiber sensors have been validated for physiological measurement as a potential device for smart textiles and wearable sensors. Also, developing sensors with Polymeric Optical Fiber (POF) shows promising applications in dynamic and real scenarios, as low-cost alternatives. Furthermore, the functioning of POF sensors can be used in no-skin contact applications, such as in highly skin-sensitive children with Autism Spectrum Disorder (ASD) during therapies. On the other hand, Dog-Assisted Therapy (DAT) is a stress-reducing method and has been studied to identify its influence on improving therapies and stress-related events. This work presents a case study in three weekly DAT sessions focused on speech therapy in a subject with ASD. A validated low-cost POF sensor was used in this first dynamic physiological measurement scenario. The analysis of five Heart Rate Variability (HRV) variables was made to compare the participant's physiological status before and during the DAT. The obtained pulse signal showed the dynamic movements affecting the signal but being able to obtain the pulse peaks. The physiological comparison showed a difference in the mean peak-to-peak time interval when the child was interacting with the dog than previous to the interaction in Session 1 and Session 2 (p-value<0.05). Also, an improvement in phonological consciousness was obtained, increasing by eight points after the three weeks of therapy. This case study showed the potential use of POF sensors in dynamic environments, and for wearable or smart textiles for children with ASD.

1 Introduction

Autism Spectrum Disorder (ASD) is a complex neurodevelopmental condition characterized by persistent challenges in social interaction, communication, and repetitive behaviors [1]. The prevalence of ASD has been increasing globally, making it a significant public health concern [2]. Individuals with ASD often experience a range of comorbidities, including anxiety, sensory sensitivities, and difficulties with motor coordination, which can complicate their daily functioning and quality of life [3, 4].

Conventional therapies for ASD typically involve a combination of behavioral interventions, educational strategies, and sometimes pharmacological treatments [5, 6]. Applied Behavior Analysis (ABA) is one of the most widely used approaches, focusing on reinforcing positive behaviors and reducing harmful or undesired ones [7]. Despite the effectiveness of these therapies in many cases, they often require significant time, resources, and specialized training, which can be barriers to access for some families [8].

Speech therapy is a critical component of the therapeutic regimen for many individuals with ASD [5]. This intervention aims to improve verbal and non-verbal communication skills, which are often significantly impacted in this population. Speech therapists work on language development, articulation, social communication skills, and alternative communication methods when necessary [9]. Enhancing communication abilities can greatly improve the overall quality of life and social integration for individuals with ASD.

Dog-Assisted Therapies (DAT) have emerged as a complementary approach to traditional ASD interventions [10]. These therapies leverage the effects of the interactions between humans and dogs to promote physical, emotional, and social well-being [11]. Interaction with therapy dogs has been shown to reduce anxiety, improve social interactions, and provide sensory comfort to individuals with ASD [12]. The non-judgmental nature and unconditional affection of therapy dogs can create a safe and motivating environment for therapeutic activities.

In this case, therapy dogs can be useful in therapies of stress management strategies, and the impact of therapy dogs can be quantified through the analysis of the Autonomic Nervous System (ANS). The ANS is crucial in regulating physiological responses to stress, when dysregulation of the ANS, often observed in individuals with ASD, can manifest as heightened stress responses, impacting overall health and well-being [10]. Understanding and monitoring ANS activity can provide valuable insights into the stress levels and physiological state of individuals

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with ASD, which is essential for tailoring effective therapeutic interventions [13]. However, in Chile, there are few canine assistance centers, and most studies of this type of therapy do not perform monitoring during the session due to the movement and activity during the therapies. Performing stress measurements at specific points of the session limits the confidence of the monitoring information because the ANS is highly regulated and changes in time.

Heart Rate Variability (HRV) is a key indicator of ANS function and overall cardiovascular health. HRV measures the variation in time intervals between heartbeats and is influenced by the balance between the sympathetic and parasympathetic systems of the ANS [14]. Higher HRV is generally associated with better adaptability and resilience to stress, while lower HRV indicates increased stress and potential health risks [15]. Monitoring HRV can offer a non-invasive and objective measure of stress and autonomic regulation in individuals with ASD [16].

Advancements in sensor technology have revolutionized the ability to monitor physiological parameters in real-time [17]. However, while accurate, there are uncomfortable sensors for children with ASD, who tend to avoid unfamiliar items and devices that come in direct contact with their skin [18, 19]. Optical fiber sensors, in particular, Polymeric Optical Fiber (POF) sensors, offer several advantages, including low cost, high sensitivity, biocompatibility, and the ability to function in dynamic environments [20]. These sensors can be integrated into wearable devices, providing continuous and non-intrusive monitoring of physiological signals such as heart rate and HRV. Their application in therapeutic settings holds great potential for enhancing the understanding and management of ASD during DATs. In addition, the indirect measurement of respiration and pulse due to chest movement and vibration is an advantage toward commercial sensors in the case of children with ASD, who can reject unknown devices due to high sensitivity in the skin.

This work aims to evaluate the effect of DATs on HRV in a case study of a child with ASD, utilizing a proposed wearable POF sensor in a dynamic environment. By integrating advanced sensor technology with therapeutic interventions, this study aims to provide new insights into the physiological impacts of DAT and contribute to the development of more effective, personalized therapeutic strategies for individuals with ASD.

2 Methodology

The methodology described in this study was approved by the ethics committee of the Special School Club Leones Cruz del Sur and is based on analyzing six segments and five HRVs as the physiological monitoring of a participant with ASD, in rest and during a DAT, with a POF-based sensor. This section describes the sensors' operation principle, the case study, the DAT protocol, the experimental setup, and the signals and features for the analysis.

2.1 POF-based sensor

The proposed POF sensor [21], is made of SH4001 Simplex Optical Fiber Cable with Polyethylene Jacket, with a 1.0 mm Core Optical Fiber diameter, and 2.2 mm Polyethylene Jacket diameter (Mitsubishi Chemical Co., Japan). The sensor is based on the optical intensity variation concept, where a constant wavelength and intensity Light-Emitting Diode (LED) is connected through a POF to a photodetector configured with a trimmer to read as best as possible the light intensity variation [20]. The sensor has a light-sensitive area to generate a variation in the light intensity that can be detected with a photodetector [22]. A 3D-printed piece was designed to maintain the coupling between two ends of POF, having one end fixed to the 3D-printed piece connected to the LED and another free-moving end connected to the photodetector; shown in Figure 2.

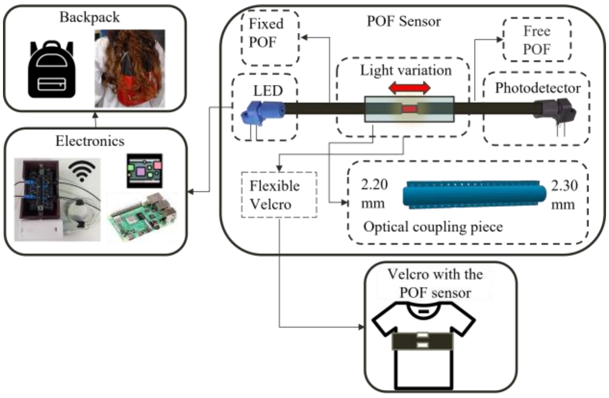

Figure 1. Diagram of the POF sensor functioning and the interrogation portable system.

2.2 Participant description

The participant is a 10-year-old boy with a diagnosis of Autism Spectrum Disorder (ASD), a user of the Rehabilitation Center Club de Leones Cruz del Sur, Punta Arenas, Chile. The participant has no respiratory, cardiac, or cardiovascular disease that could generate a high-risk situation during the session. He has no notable fear of animals, has no allergy to dogs, does not report having had any violent episodes towards an animal, and performs therapies with the dog periodically. The therapy dog has three years of experience assisting speech therapists in the institution, has all the requirements, and is a co-therapist at the rehabilitation center.

2.3 Experimental setup

The sessions were conducted in a therapy room adapted and pre-organized for the sessions, the relaxing activity material was located on a therapy table to continue with the routine of the conventional sessions. The sensor was adapted to the participant's preferences (his therapy t-shirt and backpack) and located in the room, as shown in Figure 2. The therapist ensured the participant's comfort to continue with the session. Two cameras were distributed

Table 1. Sessions flux for the procedure conducted during the case study, showing the goal of the session, and the control and DAT activities.

Session	Goal	Relax activity	DAT activity
1	To achieve identification of the initial phoneme	Cognitive control game: Set in a table with phonemic activities, with interactive cards, and boards	"Search the ball" game: Pictograms with phonetical indications glued in tenis balls asking to search the ball to the dog and asking to identify the initial phoneme to the participant
2	To achieve identification of the final phoneme		"Pressing buttons" game: Buttons indicated to press to the dog with audios with words to identify final phonemes and classifying them by the participant
3	To achieve phonemic synthesis		"Crazy cubes" game: A tower of cubes with letters are set in the middle of the room and it is indicated to the dog to take down the tower and it is asked to the participant to spell the expected word and identify the complete phonemic challenge

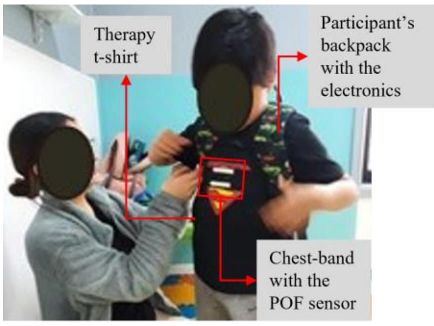

Figure 2. Location of the sensor in the participant at the beginning of the session, adapting the original sensor to the participant's preferences.

in the room to record the whole session and to monitor the sensor's functioning and control the times during the therapies, this helped to identify disconnections of the sensor by the engineer located outside the room. There was a computer at the main table to make it easier for the therapist to conduct the activities correctly and see the time of the session. The initial part of the session was conducted without the dog as the control time of therapy, and the second part was done with the dog assisting with the personalized phonetical activities for each session.

2.4 DAT procedure

This study was conducted as a case study with a pre and post-test evaluation of the standardized Phonological Awareness Screening Test (PECFO). This test was conducted also to develop a personalized therapy plan for the three sessions based on the main speech difficulties and limitations of the participant. Three DAT sessions were done, one session per week, and after this time, the PECFO test was applied again. The flow of the sessions is shown in Table 1. Before starting the study, the protocol was explained to the parents and the informed consent for participation was signed. In addition, a sensor familiarization was performed in a previous therapy to introduce the device to the participant. During the session, a resting phase

Table 2. Variables extracted from the pulse signal of the sensor with the description and processing.

Var	Description	Processing
HR	Heart rate	Counting the peaks of each 30 s window after the pulse peak detection multiplied by two
mIBI	Mean of the interbeat intervals	Mean of the detected peaks intervals of every height 30 s window
stdIBI	Standard deviation of the interbeat intervals	Standard deviation of the detected peaks intervals of every 30 s window
I2B	Mean of every two consecutive peaks	Mean difference of every two detected peaks intervals for each 30 s window
I10B	Mean of every ten consecutive peaks	Mean difference of every ten detected peaks intervals for each 30 s window

was performed to ensure that the participant was not fatigued, agitated, or stressed. The POF sensor was instrumented on the participant, and the sensor was checked for proper functioning with an interval of one minute. A baseline resting phase without the dog in the room was conducted with the control activity, and then, the therapy activity was performed with the dog. Afterward, the sensor was removed and the sessions were approximately 36 minutes, Figure 3 shows an example of the therapy room during the DAT activity with the sensor.

2.5 Processing for analysis

The results obtained from the sensors during the control and DAT activities were processed, graphically, and statistically compared, and analyzed with the HRV variables concerning the baseline to evaluate the influence of

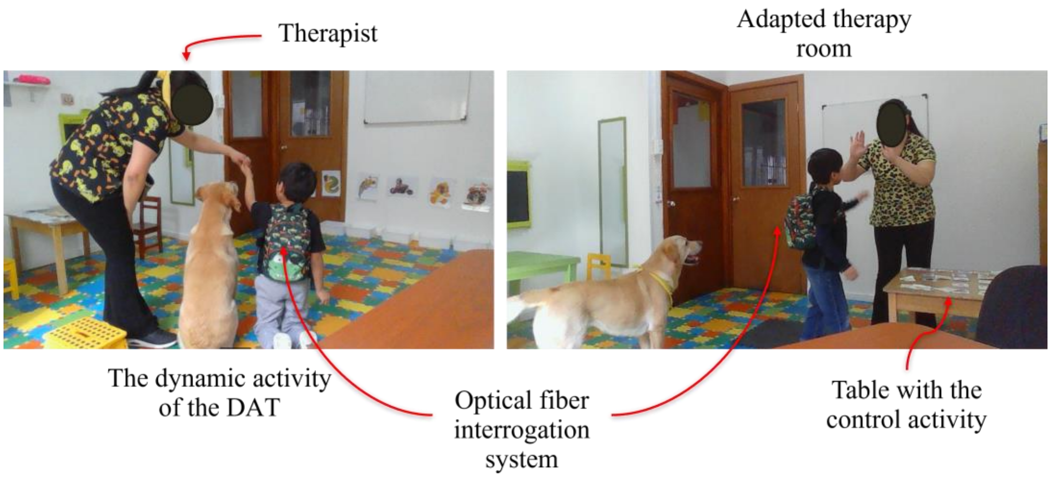

Figure 3. The therapy room as an example of the setup showing an activity during Session 2, the dog, the participant, the therapist, and the interrogation system of the sensor as a portable device.

the DAT program on the participant with ASD. Also, the PECFO test was compared before and after the therapy program.

For the POF data processing, the subject's first and last 30-second segments were omitted, and the control and DAT times were divided according to the video annotations. To confirm the frequency bands of the obtained signal with the POF, the relaxation segment was analyzed, the raw data was plotted, and the fast Fourier transformation (FFT) was performed to see the frequency bands and confirm the filtering process. The frequency bands for the biosignals correspond to the normal frequencies of heart and respiratory rates, as have been defined previously [23], from 0.1 to 0.8 Hz for the respiration and from 1 to 3 Hz for the pulse. According to the FFT with and the bands found in the literature [24, 25], a Butterworth filter was implemented for both signals. After the filtering process, the signals were verified by plotting them, as shown in Figure 4, and the Findpeaks function of Matlab was used to collect the peaks in both cases and extract the HRV variables described in Table 2.

3 Results and discussion

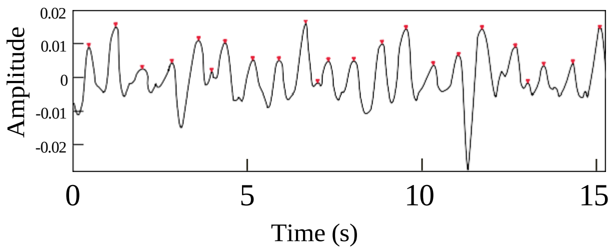

Figure 4. Pulse signal of a 15 s segment during a DAT activity of the participant.

Figure 4 illustrates the pulse signal obtained during the therapy sessions, highlighting the dynamic nature of the signal due to movements. Despite these fluctuations, the pulse peaks were successfully identified, allowing for analysis.

The physiological data, focusing on HRV, revealed a significant difference in the mean peak-to-peak time interval between sessions when the child interacted with the dog compared to before the interaction. Specifically, there was a notable change when comparing the mean peak-to-peak interval with the Wilcoxon statistical test (p-value < 0.05) during Session 1 and Session 2, as shown in Table 3. This suggests that the interaction with the dog had a measurable impact on the child's physiological state, potentially indicating reduced stress or increased relaxation during the therapy sessions.

The significant difference in the mean peak-to-peak time interval during dog interaction, as evidenced by the p-value < 0.05 in the Wilcoxon statistical test, supports that DATs can affect physiological responses. The reduction in the peak-to-peak interval indicates a potential calming effect or decreased stress levels, which aligns with existing literature on the therapeutic benefits of animal-assisted interventions [10]. This finding is particular given the dynamic nature of the pulse signal, which underscores the robustness of the physiological measurements despite potential sources of variability.

Also, with the DAT and the relation with the physiological analysis, an improvement in the PECFO assessment in the phonological consciousness was obtained. The results demonstrated an improvement in the PECFO score, with an increase of eight points following the three weeks of therapy, as shown in Figure 5. This improvement suggests that the DAT may have positively influenced the child's phonological awareness, aligning with the physiological findings.

The observed increase in PECFO scores by eight points post-therapy further corroborates the physiological findings. Improved phonological consciousness, as measured by PECFO, suggests that the therapy not only had an immediate physiological impact but also contributed to cognitive and developmental progress. This enhancement in phonological awareness may be attributed to the therapeutic environment facilitated by

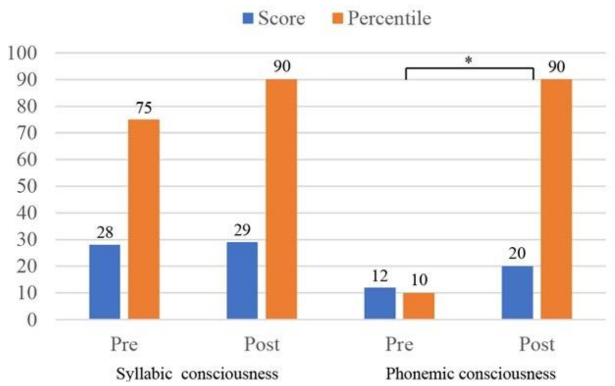

Figure 5. Pre and post-test results of the PECFO test of the participant, showing the statistical difference (*) obtained in the phonemic consciousness metric.

the presence of the dog, which could have created a more engaging and supportive atmosphere for the child.

The combined evidence from both physiological and cognitive assessments highlights the multifaceted benefits of dog-assisted therapy. The physiological data suggests a reduction in stress or anxiety, while the PECFO improvement indicates potential cognitive and educational benefits. These results align with prior studies that have reported positive outcomes from animal-assisted interventions, reinforcing the potential of such therapies in supporting both the emotional and developmental aspects of children.

Table 3. Results of the Wilcoxon statistical comparison between the control activity and the DAT in the three sessions, indicating p-values < 0.05 with *.

Var	Session 1	Session 2	Session 3
HR	0.91	0.54	0.90
mIBI	0.01 *	0.01 *	0.16
stIBI	0.02 *	0.12	0.42
I2B	0.05 *	0.61	0.22
I10B	0.39	0.18	0.70

4 Conclusion

This case study showed the potential use of optical fiber sensors in dynamic environments such as DATs as a no-skin contact device, and for wearable or smart textiles, mainly in children with ASD. In addition, it is a potential tool to identify the real impact and benefits of dog-child interactions in therapies. Future work will improve the POF-sensor's response in terms of sensitivity and performance in dynamic settings and it will be applied in other ASD therapies, to promote stress awareness and control strategies by analyzing HRV variables. While the results are promising, further research with larger sample sizes and diverse populations is needed to validate these findings. Future studies could explore the long-term effects of dog-assisted therapy on both physiological responses and cognitive development. Additionally, incorporating the evaluation of respiratory signals alongside pulse measurements could provide a more comprehensive understanding of the physiological impact of the therapy, potentially revealing how different aspects of physiological arousal are influenced by animal-assisted interventions.

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References

[1] L. Wing, The definition and prevalence of autism: A review, European child & adolescent psychiatry **2**, 61 (1993).
[2] J. Baio, Prevalence of autism spectrum disorder among children aged 8 years—autism and developmental disabilities monitoring network, 11 sites, united states, 2014, MMWR. Surveillance Summaries **67** (2018).
[3] B. Zablotsky, M.D. Bramlett, S.J. Blumberg, The co-occurrence of autism spectrum disorder in children with adhd, Journal of Attention Disorders **24**, 94 (2020).
[4] M. Micai, L.M. Fatta, L. Gila, A. Caruso, T. Salvitti, F. Fulceri, A. Ciaramella, R. D'Amico, C. Del Giovane, M. Bertelli et al., Prevalence of co-occurring conditions in children and adults with autism spectrum disorder: A systematic review and metaanalysis, Neuroscience & Biobehavioral Reviews **155**, 105436 (2023).
[5] E. Hollander, E. Anagnostou, Clinical manual for the treatment of autism (American Psychiatric Pub, 2007)
[6] R. Hurwitz, R. Blackmore, P. Hazell, K. Williams, S. Woolfenden, Tricyclic antidepressants for autism spectrum disorders (asd) in children and adolescents, Cochrane Database of Systematic Reviews (2012).
[7] H.S. Roane, W.W. Fisher, J.E. Carr, Applied behavior analysis as treatment for autism spectrum disorder, The Journal of pediatrics **175**, 27 (2016).
[8] A. Genovese, M.G. Butler, Clinical assessment, genetics, and treatment approaches in autism spectrum disorder (asd), International journal of molecular sciences **21**, 4726 (2020).
[9] M.H. Charlop-Christy, M. Carpenter, L. Le, L.A. LeBlanc, K. Kellet, Using the picture exchange communication system (pecs) with children with autism: Assessment of pecs acquisition, speech, social-communicative behavior, and problem behavior, Journal of applied behavior analysis 35, 213 (2002).
[10] R.E. Griffioen, G.J. van Boxtel, T. Verheggen, M.J. Enders-Slegers, S. Van Der Steen, Group changes in cortisol and heart rate variability of children with down syndrome and children with autism spectrum disorder during dog-assisted therapy, Children 10, 1200 (2023).

[11]F. Martin, J. Farnum, Animal-assisted therapy for children with pervasive developmental disorders, Western journal of nursing research **24**, 657 (2002).

[12]L.A. Redefer, J.F. Goodman, Brief report: Petfacilitated therapy with autistic children, Journal of autism and developmental disorders 19, 461 (1989).

[13]M. Espinosa, L. Escobedo, SATORI: a support tool for young adults with autism to self-manage stress and anxiety, in X Latin American Conference on HCI (2021)

[14]S.K. Schäfer, F.R. Ihmig, K.A. Lara H, F. Neurohr, S. Kiefer, M. Staginnus, J. Lass-Hennemann,

[15]T. Michael, Effects of heart rate variability biofeedback during exposure to fear-provoking stimuli within spider-fearful individuals: Study protocol for a randomized controlled trial, Trials 19 (2018).

[16]F. Shaffer, J.P. Ginsberg, An overview of heart rate variability metrics and norms, Frontiers in public health (2017).

[17]R. Castaldo, L. Montesinos, P. Melillo, C. James,

[18]L. Pecchia, Ultra-short term HRV features as surrogates of short term HRV: A case study on mental stress detection in real life, BMC medical informatics and decision making 19 (2019).

[19]M. Gjoreski, M. Luštrek, M. Gams, H. Gjoreski, Monitoring stress with a wrist device using context, Journal of biomedical informatics 73 (2017).

[20]N.E.J. Asha, R. Khan et al., Low-cost heart rate sensor and mental stress detection using machine learning, in 5th International Conference on Trends in Electronics and Informatics (IEEE, 2021).

[21]C. Kyriacou, R. Forrester-Jones, P. Triantafyllopoulou, Clothes, sensory experiences and autism: is wearing the right fabric important?, Journal of Autism and Developmental Disorders 53, 1495 (2023).

[22]A.G. Leal-Junior, C.A. Diaz, L.M. Avellar, M.J. Pontes, C. Marques, A. Frizera, Polymer optical fiber sensors in healthcare applications: A comprehensive review, Sensors 19 (2019).

[23]M. Gaitán-Padilla, M. Múnera, M. Pontes, M. Segatto, C. Cifuentes, C. Diaz, Development of a polymeric optical fiber sensor for stress estimation: A comparative analysis between physiological sensors, IEEE Sensors Journal (2024).

[24]J. Casas, A. Leal-Junior, C.R. Díaz, A. Frizera, M. Múnera, C.A. Cifuentes, Large-range polymer optical-fiber strain-gauge sensor for elastic tendons in wearable assistive robots, Materials 12 (2019).

[25]D.L. Presti, D. Bianchi, C. Massaroni, C. Coricciati, A. Rainer, S. Silvestri, A. Gizzi, E. Schena, Optimization and characterization of a 3d-printed wearable strain sensor for respiration and heartbeat measurements, Measurement p. 114377 (2024).

[26]L. Zhichao, Z. Xi, S. Taoping, M. Jiahe, Heartbeat and respiration monitoring based on fbg sensor network, Optical Fiber Technology 81, 103561 (2023).

[27]A.G. Leal-Junior, C.R. Díaz, C. Leitão, M.J. Pontes, C. Marques, A. Frizera, Polymer optical fiber-based sensor for simultaneous measurement of breath and heart rate under dynamic movements, Optics & Laser Technology 109 (2019).