Designing a Smart Ring and a Smartphone Application to Help Monitor, Manage and Live Better with the Effects of Raynaud's Phenomenon

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Abstract. This paper presents the research, the preliminary design stages and an early evaluation of a digital wearable product for monitoring and managing the effects of a chronic disease called Raynaud's phenomenon (RP). The proposed wearable prototype aims at supporting sufferers in their everyday life for managing and preventing RP. The product is composed of three main parts, a physical product of a smart ring, the digital infrastructure of the physical computing subsystem (hardware and software) and an accompanying mobile application.

Keywords: Raynaud's phenomenon · Wearable health technologies
Smart ring

1 Introduction

Digital health is a well-established scientific and industrial domain while the introduction of wearable health technologies that monitor human activity in real-time and provide information for managing health related issues is a relatively new research area that combines, product and industrial design with computing, data analytics and healthcare [1, 2].

The broader scope of digital health and health wearables is to provide patients with technologies (hardware devices, software tools/systems and online services) to better monitor, track and eventually manage their health and wellness related activities. The line between consumer health wearables and specialised medical instruments begins to blur primarily because of the continuous improvement of the former in terms of accuracy, efficiency, aesthetics and form factor. Their use is changing the way people think about their health, but also provide the means to understand and anticipate health progress by (a) providing innovative ways to monitor health and well-being, (b) give greater access to information and (c) support communication and collaboration. According to Lupton [3], digital health technologies and in particular digital health wearables are described as "products that encourage lay people to engage in preventive health activities and improve patient adherence to treatment protocols and their self-management of chronic diseases". Moreover, such technologies afford human

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interaction and communication at various levels, including those between healthcare providers and patients but lately, also, among patients and other stakeholders over social network platforms [4].

In this project attention is given to a specific group of people who suffer from RP. In the following paragraphs, we analyse RP and its major characteristics that can be monitored and possibly managed through the use of wearable health technologies. We provide an overview of related projects and present our research, preliminary design stages and an early evaluation of a digital wearable product for monitoring and managing the effects of the chronic disease. Finally, we also outline some insights for future work.

2 Raynaud's Phenomenon

People who suffer from RP very often experience cold fingers, toes and other extremities when they are exposed to cold or stressful situations [5–7]. The typical presentation of a RP event involves the fingers turning white (ischemia), then blue (cyanosis), and finally red (reperfusion). Those events are described as cold 'attacks'. RP appears in 5 to 10% of the world's population with women representing 90% of them. The phenomenon is either described as *Primary* or *Secondary*. *Primary RP* occurs by itself (as a disease) by unidentifiable reasons and can't be cured. *Secondary RP* is considered an expression of another underlying disease which, if identified and managed, it consequently cures RP as well. Both types have common symptoms, but the attacks can differ on symmetry, severity, frequency and duration and can be distinguished with clinical criteria.

Patient education for *prevention* is inseparable part for managing Raynaud's successfully. It is considered that patients should take proper precautions for avoiding direct interactions with cold objects and environments. Multilayered clothing, glove liners, electric gloves, pocket heaters are essential for keeping the core body and extremities warm during the cold months [6]. A healthy eating, non-smoking lifestyle with daily exercising or meditation can help improve circulation and relieve stress in the long-term.

Typical clinical diagnostic investigations include blood count, ESR and ANA analyses, and nailfold capillaroscopy among others. These methods are expensive, available only in specialist centers [8] and require dedicated medical equipment: thermography, arterial Dopplers, large vessel imaging with X-ray, CT or MR angiography. The use of the "cold-challenge test" is often considered the standard measuring/testing mechanism for diagnosing RP while other testing techniques such as the 'distal–dorsal difference' (DDD) in temperature (hypothesis that the tip of a finger is >1 °C colder compared to the dorsum of the hand at room temperature of 30 °C), also help to identify and differentiate RP from other conditions [9].

2.1 Benefits of Monitoring Raynaud's

Monitoring RP as a process has a great potential in managing the disease at various stages in its progress. The benefits can be summarised in the following: *Identify the* *progress of the disease:* Sensors can alert on abnormal body temperature or blood pressure drops that could indicate a Raynaud's attack. Continuous monitoring of severity, duration and frequency of attacks can help in keeping a detailed record of past events automatically. By analysing the stored patterns of occurrence, it is possible to provide insights for the characteristics of future events. Monitoring can also assist in detecting a transition to *secondary* RP as it happens to 2% of patients every year year [10]. Monitoring can also help in identifying specific conditions (e.g. digital ulcerations) that occur during the course of RP and thus provide the grounds for educating users to reduce risks (e.g. scarring or gangrene). *Track and monitor treatment:* Before engaging a patient to a specific treatment plan, the relative risks and benefits must be considered [7]. Thus, monitoring how patients' organisms react to a certain therapy can help identify early benefits or unforeseen risks. Digital health technologies have the potential to monitor the recovery processes that occur with a specific treatment phase and to detect improvements or complications as they arise. Captured data can be analysed and potentially utilised in measuring the effectiveness of a treatment. *Improve self-management:* Adjust behaviour or get motivated for better health e.g. insight to stop smoking. Develop proactive mechanisms to identify and anticipate a 'cold' attack. Engage in a more proactive/prevention lifestyle. Train on thermal biofeedback. Organise post-attack actions. Understand the effects and severity of an attack. *Build a community:* Benefits include the sharing of experiences, confessions, ideas, empirical methods for helping RP. Users can ask questions and exchange information related to their condition (forum). Direct contact with doctors and caregivers. Read news on research, medications, treatments etc. *Develop useful knowledge from raw data:* The psychological nature of RP makes patients evaluate their health status by means of subjective empirical judgments. On the other hand, it is important to gather objectively measured data that can help in assessing the effectiveness of treatment plans. Data acquisition and analysis can provide both users and health professionals with new knowledge on how everyday habits, treatments and behaviors affect RP.

3 Related Work

Today's wearable devices enable real-time monitoring with the aim of self-care and prevention [2, 11]. Heart rate, blood pressure and oxygen saturation are usually measured within the contexts of a physician's office but health wearables are bound to change that [4, 12]. The same measurements can easily and accurately be acquired from today's state-of-the art sensors. Tracking physiological parameters helps provide instant feedback to users, doctors and caregivers by the time a measurement starts getting abnormal. Algorithms can correlate findings and identify patterns that may reveal interesting physiological responses of the body during different activities and environments [4, 13]. Wearable devices can help understand user routines and their baseline norms so as to inform on abnormal changes [13, 14] (e.g. changes in baseline heart rate or skin temperature when waking up). Data analysis can reveal differences among individuals with different health statuses (e.g. those with *Primary* Raynaud's versus those with *Secondary*). They can identify and inform people on habits that have positive or negative impact to their health [14]. Modern wearables can assist users on early medical diagnosis, inform on disease development, track multiple parameters, keep doctors and caregivers updated real-time.

3.1 Related Projects

As of today, there are no low budget, consumer targeted wearable devices (non-medical instruments) or smartphone applications dedicated in tracking continuously and in real-time Raynaud's phenomenon that aim at supporting end-users/patients outside a clinical environment. We identified the following two experimental projects that are related to RP and aim at providing such a service to end-users/patients. In 2002, researchers from John Hopkins University developed a portable device that would wrap around a fingertip to measure RP symptoms at a domestic environment. It featured two temperature sensors for measuring skin and ambient temperatures while the use of a button recorded these values that could later be exported to a computer for further analysis. The device was re-patented in 2005, but no updates on design or user trials are reported ever since [15]. Another monitoring prototype for RP was developed in 2016 as a proof-of-concept for a hackathon event [16]. It featured two temperature sensors; one attached at the wrist and one at the finger in the form of a ring. The project's evaluation mechanism is similar to the 'distal-dorsal difference' hypothesis. The developer's ambition was to create a platform to collect and process everyday data but the project was stalled and no publications were reported.

4 Methodology, Design and Prototyping

4.1 Methodology

The methodology used in this work is based on a mix and match of techniques [17], methods and methodologies used in designing interactive systems and services [18, 19]. It is mainly a multi-methodological approach influenced by interaction design and user experience design that extends to software, systems and service design and industrial design. It encompasses design goals focusing in dealing with product's behavior (physical product and computational, data analytics), visual and physical form, interactivity and user experience. The research and design processes that we followed [20, 21] involved techniques for: project planning; conducting preliminary desktop research (bibliographic, internet); research by collecting data (PACT) [22] and modeling raw information; defining requirements; laying out a basic design framework; designing prototypes and evaluation.

4.2 Design and Prototyping

Design Requirements

According to a recent study, functionality and aesthetics gain surprisingly increased attention among a total of 22 user requirements when it comes to using wearable wellness devices [23]. People prefer lightweight, comfortable, durable and pleasing to use wearable devices that add value to their life. For these reasons, our design requirements for the physical product of the designed ring aim at unobtrusive design and interactions, elegant and minimal aesthetics, durable, waterproof and medical grade materials. Emphasis should be given to the physicality of the interaction where tangible and embodied interactions play a major role and coexist with graphical user interfaces (UIs) that are presented on the mobile application. The device should provide intuitive interaction and user experience and should adapt to the user's everyday activities in a continuous and non-intrusive way. The device must be context-aware and capable of alerting its users when the environment becomes risky, i.e. a 'cold' attack is imminent. Technical requirements include the use of tiny, fast-responding sensors for capturing data (temperature, humidity and skin conductance) and small output actuators for informing and providing feedback (tactile, visual). Data analysis should provide information about user's activity, the context of use, potential psychological distress and the overall RP status by comparing the different patterns of logged data. Other technical requirements include a long-lasting battery and a remote charging capability, as well as means for communicating with a mobile application (e.g. Bluetooth, NFC). The accompanying smartphone application should work as an instant feedback medium to let users monitor and gain insight on their health status. It must keep track of the severity, duration and frequency of RP attacks. The minimum industrial requirements should be related to usability and ergonomics while tangible interactions should focus on delivering maximum integration of the program in everyday life and maximum user experience. At a higher level, the final product (ring and mobile application) must support interactions among patients, doctors and caregivers and provide the means for sharing newly created information to online RP communities. Finally, the product must lead to behaviour change, supporting users for a healthier lifestyle by promoting the values of prevention and active engagement.

Industrial Design

Industrial design is an important stage for this project. It prioritises functionality and aesthetics as an attempt to avoid stigma and misperceptions of assistive technologies. People who use wearable medical devices in their everyday life are often stigmatised and socially discriminated and those who experience RP are not an exemption (cold, pale-colored hands, recovery actions). Therefore, the design of the physical artefact focusses in raising users' self-confidence while minimising the levels of psychological distress caused by social factors (Fig. 1).

The proposed design of the smart ring aims to be indistinguishable from other jewelry. Its form refers to state-of-the-art smart devices with CNC-engineered 0.4 mm titanium shell. The parts are designed for a solid, sealed assembly to allow high levels of water, scratch and drop resistance. The body of the ring is 10 mm wide and 2.4 mm thick, like most metal rings while actual sizes (inside diameter and circumference) may vary. The inner cylindrical part is made of tough, non-slippery medical grade silicon to ensure grasping and avoid skin irritation.

The internal components include three temperature sensors (environment temperature sensor T1, inner 'object-in-contact' temperature sensor T2 and finger temperature sensor T3), a humidity sensor (HM) placed on top and an electrodermal activity (EDA) sensor for monitoring changes in skin conductance. A flex circuit accommodates the microcontroller unit (MCU), a 3-axis accelerometer (ACC), and a

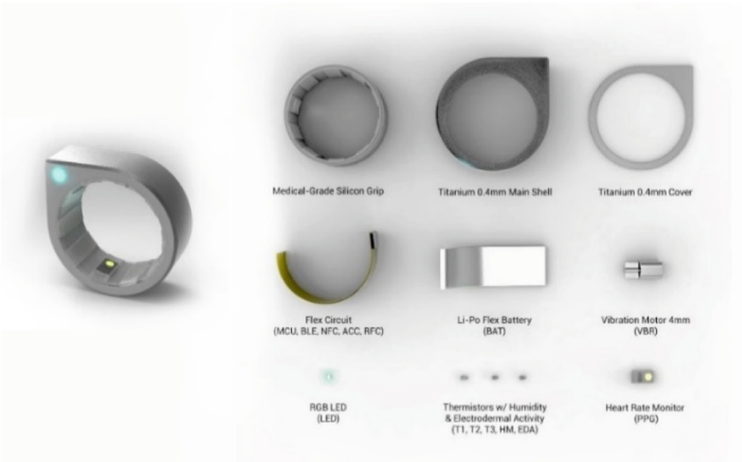

Fig. 1. Physical product of the smart ring and its characteristics, components.

radiofrequency power receiver (RFC) for charging the ring without any cables. The curved Lithium-Polymer (Li-Po) battery is 1.3 mm thick, 26 mm long and 8 mm wide (1.3 × 8 × 26 mm). Its capacity is estimated to be enough for a two-day battery life (10–20 mAh). The BLE protocol ensures tiny power consumptions and deep sleep modes for when the device is not in use. In the following Table 1 we present how each component contributes to monitoring user's activity and RP symptoms.

Mobile Application and User Experience

The mobile application functions in relation to the ring device and supports automatic sensor data acquisition or manual manipulation of data and other customisations by the end user (personalisation, custom data entry, setting up goals etc.).

It aims in providing useful information for managing and monitoring the course of the disease (log of RP attacks, heartbeat status, temperature, estimated stress levels, user's activity e.g. running, walking, sleeping etc.), it affords online communication mechanisms and synchronisation with third party online applications and services.

The interface is intuitively designed to provide a reliable and pleasing user experience (gradient colors indicate the risk factor, temperature changes can be announced by audible feedback). Device status can be monitored by the user at various levels including proximity and ring's remaining battery life.

Other functionalities include: *Daily insight* for motivating users, *Track an Activity* for detailed analysis of user's activity and goals and in relation to the potential risks for having a RP attack (UI3 at Fig. 3), *Treatment Plan* for managing treatment or medication plans (Info section at Fig. 2 and UI2 at Fig. 3), *Achieve goals* for managing and setting goals related to RP (e.g. proposed by therapist or online by a community, a challenge etc.), *History log* of RP attacks, medicine intakes, tracked activities, achievements and notes are sorted out in a calendar which functions as a detailed history log (UI4, UI5 at Fig. 3), *Share with Doctors* for sharing logged data with doctors, *Make notes* for custom logging and notetaking, *Community of users* for connecting with other users, online communities and services.

Table 1. Electronic components and their role in the smart ring.

	ID	Component type	Role
Input	T1	Environment thermistor	Monitor temp. of environment or object's that covers the finger. (e.g. glove)
	T2	Object-in-contact-thermistor	Monitor the temperature of the things that the user holds or touches with their palm. If hand is on air, it also measures the environment's temperature
	T3	Finger thermistor	Constantly monitors the temperature of the finger. A dangerous temperature drop turns on the PPG sensor to verify the absence of pulse
	EDA	Electrodermal sensor	Skin conductance, sweat rate, psychological distress, water presence
	HM	Humidity sensor	Environment humidity sensor, water presence or absence. Humid environments can trigger a RP attack even when temperature is high
	PPG	Photoplethysmography (PPG) sensor	Measure blood volume changes, monitor heart rate (HR) and heart rate variability (HRV), detect the absence of pulse which indicates a RP attack
	ACC	3-axis accelerometer	Detect user activity (e.g. walk, run) and input gestures (e.g. tap twice for checking RP status or tap three times for checking battery level)
Output	VBR	4 mm vibrator	Receive alerts when environment becomes risky. Feedback to user inputs
	LED	RGB LED	Feedback to user interactions. RGB to represent RP status or battery level
MC unit	MCU	System on Chip (SoC) Microcontroller Unit (MCU)	Microprocessor with integrated Bluetooth Low Energy (BLE) chip and Near Field Communication (NFC) for very low energy consumption
Power	BAT	Flexible (Li-Po) battery	Flexible custom design to fit the product. 2 days of battery life
	RFC	Radio-frequency (RF) wireless charging chip + nest (e.g. Humavox's Thunderlink)	Tiny wireless power receiver located in the ring. Requires a 'nest' where a wireless power transmitter can be implemented to start charging the device when in close proximity
	OTG	On-the-go charger	Accessory to charge ring from smartphone

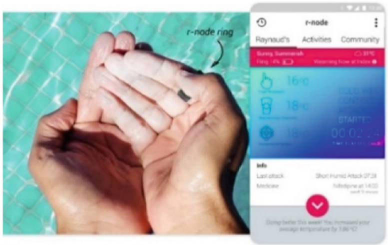

Fig. 2. Wearable ring device and application interface.

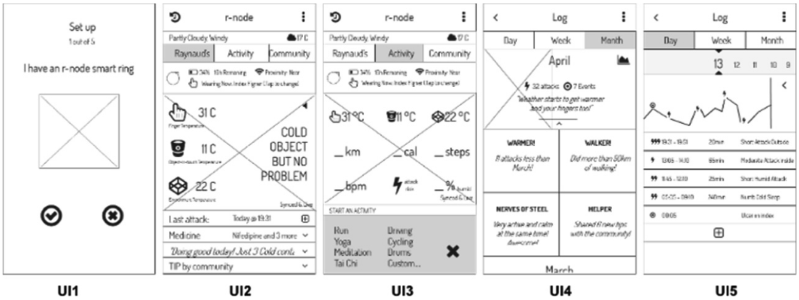

Fig. 3. Low fidelity design of user interfaces. Made using Balsamiq Mockups 3.

The basic interactions and functionalities of the tangible product include a number of gestures for (a) providing feedback in case of an RP attack (upon detection and validation of an attack a system feedback is provided to the user by a specific vibration pattern) (b) a double-tap gesture at the top of the smart ring provides the current status (visual feedback through an RGB led turns a specific color for indicating the current status of the finger) (c) a triple-tap gesture indicates battery level.

To support maximum portability and autonomy the device will charge directly from the user's smartphone using *On-the-go charging* while the *Drop-n-charge* functionality at the 'nest' case will allow wireless charging.

5 Evaluation and Results

At this stage of development three prototypes were designed and evaluated; a *cardboard prototype* for supporting ideation and early ergonomics testing, a *3D printed version of the actual* ring for the evaluation of the final form factor (size, components fitment), ergonomics (sizing, comfort), manufacturing and embodiment and a *working prototype* (wearable ring with electronics and the accompanying Android application) (Fig. 4).

Evaluation was performed in two stages. Initially we did a set of Expert Reviews with double experts for getting fast results, followed by a thorough User Testing. For

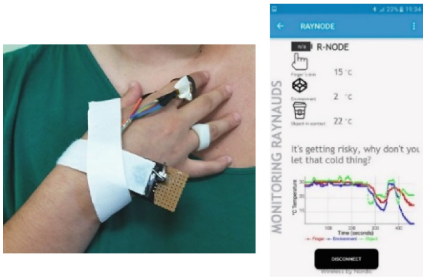

Fig. 4. Working prototype and its application interface.

the later a total of four (n = 4) subjects were recruited to evaluate the prototypes (one diagnosed with RP) under a mixed (CW + HE) cognitive walkthrough and heuristic evaluation usability evaluation method. User subjects followed a specific scenario with a predefined number of tasks (t = 27). Subsequently, a hybrid usability/aesthetics questionnaire was answered.

Evaluation findings show that user subjects believe the application can *help in disseminating scientific knowledge* and *empirical methods* for managing RP, it can *assist communication between patients and health professionals* and *motivate users adopt life-changing behaviours* in the long term. Overall usability and aesthetics received positive comments. We also collected a number of recommendations, both from experts and users, regarding the data analytics and visualisation.

6 Conclusion and Future Work

We identify the potential of a minimal non-obstructive digital health wearable which can monitor and assist in managing the effects of RP at a cost-effective and aesthetically pleasing way for the user. We mainly aim to promote behavior change through minimal everyday interaction with a wearable product and provide accurate information to the end user through data analytics. User experience and interaction design for wearable health technologies, further exploration of the DDD hypothesis and cloud computing for scalable big data analytics are important domains that we intent to further explore in our future designs and research. Instead of designing a single product or application we aim at developing an ecosystem that is composed of several subsystems including a physical product, the online platform and its accompanying cloud and data analytics services [24] and a mobile application for the end users to interact with.

References

1. Pantelopoulos, A., Bourbakis, N.G.: A survey on wearable sensor-based systems for health monitoring and prognosis. IEEE Trans. Syst. Man Cybern. **40**, 1–12 (2010)
2. Chan, M., Estève, D., Fourniols, J.-Y., Escriba, C., Campo, E.: Smart wearable systems: current status and future challenges. Artif. Intell. Med. **56**, 137–156 (2012)

3. Lupton, D.: The digitally engaged patient: self-monitoring and self-care in the digital health era. Soc. Theory Health **11**, 256–270 (2013)
4. Piwek, L., Ellis, D.A., Andrews, S., Joinson, A.: The rise of consumer health wearables: promises and barriers. PLoS Med. **13**, e1001953 (2016)
5. Andrews, J.: Maurice R Raynaud and his protean disease. J. Med. Biogr. **5**, 46–50 (1997)
6. Wigley, F.M.: Raynaud's phenomenon. N. Engl. J. Med. **347**, 1001–1008 (2002)
7. Marcus, S., Weiner, S.R., Suzuki, S.M., Kwan, L.: Raynaud's syndrome. Postgrad. Med. **89**, 171–187 (1991)
8. Herrick, A.L.: The pathogenesis, diagnosis and treatment of Raynaud phenomenon. Nat. Rev. Rheumatol. **8**, 469–479 (2012)
9. Anderson, M.E., Moore, T.L., Lunt, M., Herrick, A.L.: The "distal-dorsal difference": a thermographic parameter by which to differentiate between primary and secondary Raynaud's phenomenon. Rheumatology **46**, 533–538 (2007)
10. Hirschl, M., Hirschl, K., Lenz, M., Katzenschlager, R., Hutter, H.-P., Kundi, M.: Transition from primary Raynaud's phenomenon to secondary Raynaud's phenomenon identified by diagnosis of an associated disease: results of ten years of prospective surveillance. Arthritis Rheum. **54**, 1974–1981 (2006)
11. Chatterjee, S., Price, A.: Healthy living with persuasive technologies: framework, issues, and challenges. J. Am. Med. Inf. Assoc. **16**(2), 171–178 (2009)
12. Li, X., Dunn, J., Salins, D., Zhou, G., Zhou, W., Schüssler-Fiorenza Rose, S.M., Perelman, D., Colbert, E., Runge, R., Rego, S., Sonecha, R., Datta, S., McLaughlin, T., Snyder, M.P.: Digital health: tracking physiomes and activity using wearable biosensors reveals useful health-related information. PLoS Biol. **15**, e2001402 (2017)
13. Chiauzz, E., Rodarte, C., DasMahapatra, P.: Patient-centered activity monitoring in the self-management of chronic health conditions. BMC Med. **13**, 77 (2017)
14. Patel, M.S., Asch, D.A., Volpp, K.G.: Wearable devices as facilitators, not drivers, of health behavior change. Jama **313**, 459 (2015)
15. Wigley, F.M., Wise, R.A., Schwartz, P.D., Lew, A.L., Scott, D.D., Le, B.Q.: Ambulatory surface skin temperature monitor (2005). http://www.google.ch/patents/US6847913
16. Jean, J.: Portable Raynaud Monitoring Device (2016). https://hackaday.io/project/17998-portable-raynaud-monitoring-device
17. Taket, A., White, L.: Partnership and Participation: Decision-Making in the Multiagency Setting. Wiley, Hoboken (2000)
18. Gothelf, J., Seiden, J.: Lean UX: Applying Lean Principles to Improve User Experience. O'Reilly Media, Inc., Sebastopol (2013)
19. Preece, J., Sharp, H., Rogers, Y.: Interaction Design: Beyond Human-Computer Interaction. Wiley, Hoboken (2015)
20. Goodwin, K.: Designing for the Digital Age: How to Create Human-centered Products and Services. Wiley, Hoboken (2009)
21. Cooper, A.: About Face: The Essentials of Interaction Design, 4th edn. Wiley, Indianapolis (2014)
22. Benyon, D.: Designing Interactive Systems: A Comprehensive Guide to HCI and Interaction Design. Pearson Education Canada, Harlow; New York (2010)
23. Rantakari, J., Inget, V., Colley, A., Häkkilä, J.: Charting design preferences on wellness wearables. In: Proceedings of the 7th Augmented Human International Conference 2016 on - AH 2016, pp. 1–4. ACM Press, New York (2016)
24. Zhang, Y., Qiu, M., Tsai, C.-W., Hassan, M.M., Alamri, A.: Health-CPS: healthcare cyber-physical system assisted by cloud and big data. IEEE Syst. J. **11**, 88–95 (2017)