Report

# Personalised context-aware digital health interventions: crossing boundaries between data science, geoscience and health psychology

**Monique Simons**
*Wageningen University & Research, Netherlands*
**Arend Ligtenberg**
*Wageningen University & Research, Netherlands*
**Felix Naughton**
*University of East Anglia, UK*
**Susan A Murphy**
*Harvard University; Cambridge, MA, USA*
**Laura M. König**
*University of Bayreuth, Germany*
**Laura Winkens**
*Wageningen University and Research, Netherlands*

## Introduction

This paper reflects the discussions at the roundtable on Just-In-Time Adaptive Interventions (JITAIs) (Nahum-Shani et al., 2018) held at the European Health Psychology Society (EHPS) conference 2022 in Bratislava. JITAIs are a novel class of digital health interventions that capitalize on technological developments around wearables, data and data science methods to develop personalized context-aware health behaviour change interventions. This novel intervention design is promising because of its ability to capture the dynamics and complexity of health behaviours.

In this roundtable, convened by Monique Simons, four researchers with diverse disciplinary backgrounds (i.e. data science, health psychology, nutrition science, geoscience) shared their knowledge and experiences with JITAIs for promoting healthy lifestyles. Topics included reinforcement learning by Susan Murphy, geofences triggered behavioural support by Felix Naughton, opportunities and challenges of JITAIs in the healthy eating domain by Laura König, and spatial data by Arend Ligtenberg. By discussing and sharing with the EHPS community, we gained shared insights in the opportunities and challenges on developing, evaluating and optimizing JITAIs for promoting healthy lifestyles. In the current paper we combine and share these insights in order to expand our community and advance collaboration around JITAIs for promoting healthy lifestyles.

## Background: Leveraging technological developments for healthy lifestyle interventions

Adopting and maintaining a healthy lifestyle is key to health and vitality. However, adopting and maintaining a healthy lifestyle is challenging. Hence, effective behaviour change interventions are urgently needed to promote sustainable healthy lifestyles.

Technological developments create new opportunities for the design of behaviour change interventions and the dissemination of interventions (Dallery et al., 2015). Digital and mobile intervention platforms (e.g. smartphone apps and smartwatches) in combination with wearables and smartphone built-in sensors (e.g. accelerometery, heart rate sensor, GPS), increase scalable opportunities to deliver health lifestyle interventions and make it possible to acquire real-time data on health behaviours in a continuous and non-obtrusive way, resulting in high resolution

and high dimensional data (e.g. environmental and psychological factors) (Marsh, 2021; Chevance et al., 2021). These highly individualised and contextualised behavioural assessments provide new opportunities for novel intervention designs such as JITAIs. By taking into account contextual factors and by adapting the intervention over time based on people's behaviours and responses to the intervention, we are able to develop precise and highly personalized interventions, such as JITAIs. Such precise and highly personalised interventions hold the promise of increased effectiveness and impact (Fisher et al., 2018). JITAIs can thus be seen as a concrete example of the emerging concept of personalised health (Collins and Varmus, 2015), which is aimed at shifting from traditional group-level approaches to approaches that are individualised, contextualised and timely (Hekler et al., 2020; Chevance et al., 2015).

## Just-in-Time Adaptive interventions: challenges and opportunities

### *Challenge 1: Adding geographic space*

As mentioned above, awareness of the context of a JITAI user is crucial for providing highly personalised interventions. For most current JITAI systems, support delivery is mainly defined by time, hence 'just in time'. Here we argue that for many, if not most JITAI applications, space/place is a key factor for defining context. Where we are and where we go strongly affects our behaviour and decisions. Additionally, spatial-temporal conditions are likely to strongly determine the effectiveness of an intervention. For JITAI systems with a focus on healthy lifestyles, location is considered to play an important role. Coupling the 'where' to the 'when' might help to raise the quality of interventions. As an example, Naughton et al. (2016, 2021) developed and tested a JITAI for smoking cessation using smartphones and geofencing techniques. Places where people were vulnerable to smoking (home, pubs, friends house etc.) were determined using a geofence. When a user entered or dwelled in such geofences, behavioural support, tailored to identified contextual cues specific to those locations, were delivered.

Besides these relatively straightforward geofencing techniques the domains of geography and geo-information sciences developed a whole range of additional concepts, methods and tools that are helpful to analyse interactions between people and their spatial environment (Shaw and McGuire 2017). Analyses that include the proximity, topology, density, and visibility of spatial features allows for a richer representation of the context and more targeted interventions. Challenges here are the complexity of the data. To be able to use the geographic context, spatial information from multiple sources are required, including data about the network, locations of intervention points etc. In addition, the accuracy of current built-in GPS modules in smartphones does not always provide the necessary accuracy, especially in urban areas. It is expected that in the near future, at least for Europe, smartphones that support the GALILEO system might overcome this problem (Fernandez-Hernandez et al., 2018).

### *Challenge 2: Adding adaptivity*

Adaptivity in JITAI systems can be viewed on two levels: 1) the level of individual behaviour; i.e., how can interventions continuously be adapted based on the state of users, to fulfil as much as possible the needs of an individual user at a certain time and place. This requires precise knowledge of

the individual's goals and traits as well as the contextual factors that affect their vulnerability and receptivity to interventions; 2) the level of the system itself; i.e., how can a JITAI application be used to understand spatial-temporal and behavioural patterns and use that information to refine interventions at the individual level and/or increase understanding of the linkages between behavioural patterns and the spatial-temporal context where these behaviours occur.

For both levels advanced machine learning (ML) techniques such as reinforcement learning (RL) are promising. RL algorithms allow the system to autonomously make intervention decisions (i.e. act as an artificial decision making agent). Hence, these techniques allow for a regular updating of the decision models to the needs and context of an individual, and thereby allowing the generation of personally tuned interventions. ML highly depends on the availability of ample data suitable to learn from. Currently, ML for these types of applications is in its infancy. The challenge here is having enough data to train such a RL algorithm to deliver personalised interventions that outperform the general/aggregated approaches (Hojjatinia et. al 2021; Perski et. al. 2022). How can we use behavioural theory/expertise to improve the speed at which a reinforcement learning algorithm can effectively personalize? How to use existing data to "warm-start" (Zhang et al., 2021), that is initialize reinforcement learning so that it will learn and personalize quickly? And in this way to shorten the learning process of the RL algorithm and minimize the burden for the users by collecting data during the intervention (Wang et al., 2021).
A complicating factor might be that it is not clear what data individuals are willing to provide in return for a higher personalisation level (i.e. personalization-privacy paradox), though this can be ameliorated when computation, and thus any personal data, can be undertaken and restricted to the device ('native app') (Naughton et al., 2021) instead of communicating with a remote server (Sporrel et al., 2021). A crucial avenue to advance this line of research further is to focus on the design and evaluation of JITAIs harnessing data-science approaches. Initial work on the development of requirements and frameworks for the use of RL algorithms for digital interventions are found in Trella et. al (2022).

## *Challenge 3: Evaluate the effectiveness of JITAI*

The adaptive nature of JITAI applications and the quickly developing technology used to build them complicate their evaluation. Instead of traditional study designs such as randomised-controlled trials, more adaptive study designs are needed to adequately test their effectiveness, including within-person designs (Kwasnicka et al., 2022). Moreover, JITAI applications have the potential to generate large amounts of data such as intervention moments, user reactions, spatial-temporal recordings etc. These big, high dimensional and high-resolution data require advanced data analysis methods, beyond the common statistical methods in health research. Modern data science approaches provide tools to engage a Knowledge Discovery Process in Databases (KDD) process to extract valuable information out of the available data (Wachowicz et. al. 2008. Fayyad 1996). This information allows us to create models, often using ML, that learn about an individual's behaviour and 'risky moments' for unhealthy behaviours, so informing when a system or Artificial Intelligence can deliver 'just-in-time' support to facilitate or maintain health behaviour change.

When an RL algorithm is driving the adaptivity and personalization of the JITAI, approaches that inspect the performance of the RL algorithm at a finer level than the usual randomised-control trial are needed. These more fine-grained evaluations can take advantage of the large amounts of data

generated during implementation of the RL algorithm. To do this, measures of confidence that illuminate whether the decision-making behaviour of the RL algorithm can be attributed to learning versus chance are needed. This is particularly the case when considering the performance of the RL algorithm at the individual level.

### *Challenge 4: Developing JITAI for consumption behaviours*

To be able to intervene just in time, JITAI systems typically use input data that is automatically collected, e.g., via wearable and smartphone sensors. While intervening based on time cues has already been implemented in the context of consumption behaviours including eating (König & Renner, 2019), it is much more challenging to intervene based on behavioural cues. This is because to capture the consumption of foods or drinks, manual user input is usually required, especially if the quality of the consumed products (i.e., healthy or unhealthy) needs to be taken into account (König et al., 2022). This tracking, however, is cumbersome for the user (König et al., 2021), and records may be incomplete or missed (Ziesemer et al., 2020). Advances in the development of automated input (e.g., via wrist-worn sensors, see Bell et al, 2020, for a review) and analysis algorithms are urgently needed for JITAI applications for consumption behaviours to gain traction. For the collected data to make sense (e.g., in terms of nutritional value which is typically the basis for feedback and interventionist messages), interdisciplinary collaboration between computer scientists, engineers, nutritional and behavioural scientists is crucial.

## Conclusion and next steps

JITAIs are a promising and fast growing area in the field of intervention design for supporting healthy lifestyles. The challenges identified highlight how the field is at its infancy. More research and collaboration are necessary to advance the field and utilize more of the possibilities of data and technological developments. Promising avenues to take are: the use of GPS and GIS in JITAIs to not only deliver 'just-in-time' but also 'just-in-place' interventions; advance the application and performance of RL algorithms in JITAIs to create truly and real-time adaptive interventions; advancing the use and development sensors to acquire input data that is automatically collected, especially in the field of JITAIs to promote healthy eating behaviours.

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**Monique Simons**
Wageningen University & Research, Social Sciences, chairgroup Consumption and Healthy Lifestyles, Wageningen, Netherlands.
**monique.simons@wur.nl**

**Arend Ligtenberg**
Wageningen University & Research, Department of Environmental Sciences, Laboratory of Geo-information Science and Remote Sensing, Wageningen, Netherlands.
**arend.ligtenberg@wur.nl**

**Felix Naughton**
University of East Anglia
**f.naughton@uea.ac.uk**

**Susan A. Murphy**
Harvard University; Cambridge, MA, USA
**samurphy@fas.harvard.edu**

**Laura Maria König**
Faculty of Life Sciences, University of Bayreuth, Germany
**laura.koenig@uni-bayreuth.de**

**Laura Winkens**
Consumption and Healthy Lifestyles chair group, Wageningen University and Research
**laura.winkens@wur.nl**