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A Taxonomy of Situation Awareness Failure Factors in Primary Care

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ABSTRACT

General Practitioners (GPs) report frustration in locating, customising and prioritising data in Electronic Health Records, which impairs their situation awareness (SA) and consequently impacts decision making and quality of care. Gaining SA in primary care before and during the clinical consultation is challenging, mainly due to barriers including time constraints, fragmented data, limitations in GP-patient interaction, usability issues of the Electronic Health Record (EHR) and information overload. This is enhanced with an increasing ageing population, and patients with multimorbidity. Timely and effective communication of information through data visualizations and visual analytics are promising avenues to address some of the GPs situation awareness needs and barriers, potentially supporting clinicians in making more accurate and rapid decisions. In this paper we propose a taxonomy of situation awareness failure factors in Primary Care, based on interviews with Primary Care GPs and Endsley's SA error taxonomy. We then discuss design implications towards enhancing situation awareness in Primary Care when using EHR systems, supporting the potential of holistic visualisations to enhance SA before and during the clinical consultation.

Keywords: Situation awareness, Decision making, Primary care, General practitioner, GP, Electronic health record, Information visualization, Data visualization, Holistic

INTRODUCTION

Primary care clinicians deal with a wide range of patients and disease areas, and need to make critical decisions, such as diagnosis, referrals, investigations, treatments and care management in a short consultation time of 10–12 mins (Patel et al. 2020; Porat et al. 2016; Porat et al. 2017). Increasingly, the primary care environment features a rise in patient complexity, an aging population, and an upward trajectory of multimorbidity where patients are likely to present multiple health conditions and issues in one consultation (Patel et al. 2020, Temte et al. 2020). Furthermore, poor usability of Electronic Health Record [EHR] systems, with fragmented and missing information can challenge the clinician's ability to ascertain the key factors and their critical features to gain and maintain situation awareness (McCarthy, 2016; Beasley et al. 2011). Reduced situation awareness increases both errors in clinical decision making and the patient risk for experiencing adverse outcomes (Savoy et al. 2020).

Electronic Health Records (EHR) are the main source of patient information in primary care, containing detailed documentation of patient data

(Aaronson et al. 2019). Whilst EHRs are expected to provide information required by primary care clinicians, to support and enhance their SA, the information is poorly organised, and presented as digital translations of paper-based charts, retaining an archaic format of visual and numerical medical data (Evans, 2016; Baron, 2007; Peek, 1993). Healthcare providers report frustration in usability, locating, customising and prioritising data (Bui and Hsu, 2010; Howe et al. 2018; Roman et al. 2017; Sinsky et al. 2014). An increase in data contributes to the information overload experienced by primary care clinicians (Furlow, 2020; Rand et al. 2018), where consequently critical findings can be missed (Singh et al. 2012; Graber, 2017), or diagnostic errors made (Rand, 2018; Singh, 2012). In scenarios of long-term illness, chronic-care or multimorbidity, the clinicians' cognitive overload is augmented (Wenzl, 2019; RCGP, 2020), and situation awareness decreased (Singh et al. 2006). Thus, there is an opportunity to enhance situation awareness at each step via more organised and meaningful displays of data (Pashaei and Gross, 2017), to aid the clinicians' SA, help them better understand a patient's situation, enhance efficiency, improve the quality of care, reduce human error (Bui and Hsu, 2010; Drews and Westenskow, 2006; Elo, 2008), and consequently support decision making (Waler et al., 2019) "*Every physician wants a balance between the most essential information without the distractions of data they could live without.*" (Prasad, 2016).

Previous studies of medical scenarios in primary care shows that errors in practice are linked to deficiency in one of the four levels of situation awareness: 1. information perception, 2. information comprehension, 3. forecasting future events and 4. selecting an appropriate action (Graber et al. 2017; Murphy et al. 2019; Powell et al. 2020; Singh et al. 2012). In our previous study (Patel et al. 2020), we explored opportunities in enhancing physicians' situation awareness and reducing their cognitive overload to improve decision making and quality of care before and during the clinical consultation. Interviews with eight General Practitioners explored what important information is required before and during the GP-patient consultation to enhance situation awareness; when is the right time to display this information, what is the desired format and what are the main barriers to gaining situation awareness. The Situation Awareness model (Endsley, 1995) was used as a conceptual framework to classify emergent themes. Information visualization was proposed as having the potential to enhance situation awareness during the clinical consultation.

In this paper, we aim to map the factors that contribute to SA errors in primary care, across the four levels of SA: Level 1- gathering of data, Level 2- interpreting of information, Level 3- anticipation of future states and Level 4- selecting an appropriate action; 'what exactly should I do?'. Data from semi-structured interviews was analysed and reviewed to support the development of a SA failure factors taxonomy, in Primary Care, mapped to Endsley's SA error taxonomy (Endsley, 1995). By identifying the potential errors at each SA Level, we can better understand the factors that contribute to reduced SA in Primary Care, guiding the identification of possible solutions and interventions. The emergent taxonomy highlights and identifies improvement

opportunities at individual and system levels, which are translated into proposed implications and guidelines for practice, for future tool and system development.

SITUATION AWARENESS IN PRIMARY CARE

Situation Awareness (SA) is "the perception of the elements in the environment in a volume of time and space, the comprehension of their meaning and the projection of their status in the near future" (Endsley, 1995; Endsley, 1988). SA is a critical requirement towards providing an understanding of 'what is going on' and 'what is likely to occur next' (Salmon et al. 2009), and reduced SA is shown to increase errors in clinical decision making, resulting in adverse outcomes and patient harm (Savoy et al. 2020; Schulz et al. 2016). Conversely, higher levels of SA are linked to improved clinical outcomes (Stubbings, 2012).

Endsley's model of SA (1995) identifies three levels of SA linked to decision-making. The SA levels are incremental; Level 1 – Perception of current situation (gathering data); Level 2 – Comprehension of current situation (interpreting information); Level 3 – Projection of what can happen in the future (anticipation of future states). In the context of primary care, a fourth level (Level 4) is proposed by McGuiness and Foy (2000) - choosing appropriate action based on the first three levels – "what exactly shall I do?".

Previous research (Patel et al. 2020; Porat et al. 2016) have shown that diagnosing patients in primary care has similar phases to the situation awareness model. Patel et al. (2020) mapped four core categories to the SA model when consulting via EHR, namely: (a) gathering patient data, (b) interpreting the patient's information, (c) forecasting of future events and (d) selecting an appropriate action. Similarly, Porat et al. (2016) stipulated four key cognitive requirements when diagnosing patients: (a) retrieving information from the patient record, (b) generating diagnostic hypotheses, (c) testing diagnostic hypotheses, and (d) deciding on a patient management plan. In most cases, the initial situation assessment relied on retrieving information from the EHR and integrating it with the patient's presented problem and reason for consulting. Throughout the diagnostic process, clinicians generate and test their diagnostic hypotheses through conversing with the patient, asking questions, performing clinical examinations and investigations whilst continually integrating and interpreting the information they elicited. Each step of the diagnostic process has a cognitive requirement where the General Practitioner (GP) needs to decide what information is important and requires eliciting, make the link between information, and select an appropriate course of action. Errors in SA, including missing important information in the EHR, not referring to necessary investigations, taking inappropriate or delayed action, are the main cause of diagnostic errors, and were found to contribute to serious potential harm in primary care settings (Graber et al. 2017; Murphy et al. 2019; Powell et al. 2020; Ramnarayan et al. 2003).

Situation awareness is a critical characteristic influencing decision making and thus patient safety and quality of care. Where healthcare professionals work in complex and dynamic environments, increased SA has been shown

to improve clinical outcomes (Stubbings, 2012). Primary care clinicians are required to scan, process, and interpret an ever-increasing amount of patient data, challenging their ability to review all required and relevant information to make informed decisions that influence patients' lives. Gaining SA in primary care prior to and during the clinical consultation is challenging, due to barriers such as time constraints, GP-patient interaction, usability issues of the EHR and information overload (Patel et al. 2020). Primary care clinicians require accessible, comprehensive, timely, and accurate patient information to assist in facilitating decisions related to diagnosis, prevention, treatment, and management of acute or chronic conditions (Beasely et al. 2021; Savoy et al. 2020).

Within the healthcare domain, SA is an important concept in critical care, anaesthesia, and surgery due to the perceived urgency of tasks requiring minutes and seconds. It is easier to gain SA in contexts such as the emergency department and operating room (McCarthy, 2016), over primary care settings due to fragmented information and slow change between data, and thus SA in primary care is also less researched (Graber et al. 2017). Decision support systems have been proposed to support GPs in their different tasks, such as diagnosing patients (e.g., Kostopoulou et al. 2017; Bridgwood et al. 2018; Porat et al. 2016), supporting treatments and medications (e.g., Eghdam et al. 2011; Tory and Moller, 2004) and managing patients with complex needs (e.g., Porat et al. 2019; Chana et al. 2017). However, we are not aware of research that has focused on eliciting situation awareness needs and barriers during the clinical consultation to design interventions that will support those barriers.

Our previous findings (Patel et al. 2020) supports the need to enhance Situation Awareness prior to the GP-patient consultation; where all GPs concurred that a visual presentation, which avoids having to sift through lines and lines of text could address some of the SA issues that were identified; and suggests that information visualizations have the potential to enhance situation awareness by addressing some of the identified barriers to SA, consequently improving decision making and quality of care.

FAILURE IN SITUATION AWARENESS

A high percentage of failure in human decision making is related to errors in situation awareness (Endsley et al. 1995; Despins, 2018). Endsley's taxonomy for classifying and describing errors in SA (1995), maps factors affecting SA at each of its three levels to factors contributing to failure in SA. At a top level these are, Level 1– failure to correctly perceive the situation; Level 2 – failure to comprehend the situation; and Level 3 – failure to project the situation into the future (Endsley, 1995).

In developing the taxonomy and to better understand the factors leading to SA errors, Endsley reviewed major aviation accidents in the United States (Endsley, 1995). Healthcare organisations have also analysed and categorised adverse patient outcomes as failure of SA events (Brady et al. 2013), and subsequently focused quality improvement on improving specific levels of SA (Brady et al. 2013; Despins, 2017). A similar approach can be realised in

the (re)design of healthcare systems, to contribute to existing knowledge and develop a taxonomy of SA failure factors in Primary Care. Established error definitions at each of Endsley's three levels of SA can be used to map factors that contribute to failure in the gathering of data, interpreting of information and anticipation of future states. Identifying the aims and objectives for each level of SA in relation to the event help position tasks and responsibilities and the SA errors can be translated into practice through the creation of tools or guidelines. The main barriers and limitations to gaining SA in Primary Care based on interviews with GPs (Patel et al. 2020), can further map to and align with the SA error taxonomy. This highlights and identifies improvement opportunities at individual and system levels, thus supporting the ongoing development of situation awareness in Primary Care, consequently enhancing patient safety and quality of care.

METHODS

Towards developing a taxonomy and understanding the failure factors leading to SA errors in Primary Care, data from a prior study (Patel et al., 2020) consisting of semi-structured interviews with eight General Practitioners (GPs) highlighting 'Barriers & Suggestions by Level of SA', was further analysed and aligned to Endsley's SA error taxonomy (1995), for the 3 SA Levels. The fourth level of SA proposed by McGuiness and Foy (2000), which is specifically for SA in primary care (choosing appropriate action), was also added to the taxonomy. *See* Table 1: SA Failure Factors and Characteristics of Barriers to SA in Primary Care. The emergent taxonomy highlights and identifies improvement opportunities at individual and system levels, which are translated into proposed implications and guidelines for practice, for future tool and system development *(see* Table 2).

FINDINGS

Level 1– Failure to Correctly Perceive the Situation

In the perception of the current situation and **gathering patient data,** important patient information may not be available, or perhaps difficult to ascertain or assimilate or perceive. The *unavailability of data* and patient information can stem from established systemic failures such as the delay and lack of integration between healthcare providers. This can be augmented by patients not communicating their medical history and past consultations, through lack of memory or being fearful of past problems. At times, language barriers arising from varying demographics, where English is not the patient's first language can also contribute to poor information communication and recording thereof, resulting in patchy and missing data. Whilst GPs scan through the EHR and clinical summary, barriers such as *time limitations* can prevent GPs from looking at the patient information before the consultation, thus going into the consultation with limited to no understanding of the patient. This can result in missing significant information and making errors. Time spent on gathering and interpreting information varies depending on both the patient and presented problem/s. Looking through the EHR

Table 1. Situation awareness failure factors: characteristics of barriers to SA in primary care.

Level of SA/SA Error	Failure Factors	Characteristics of Barriers to SA
Level 1: Information Perception - *Gathering Data* Failure to Correctly Perceive Situation	• Data not available	• Delays & lack of integration between healthcare providers • Running late between consultations • Inconsistency in coding - missing/inaccessible data • Patients not knowing their medical history/consultations • Patients fearful of past medical problem, so don't mention it • Variation in demographics and thus language barriers • Some patients don't consult regularly
	• Data difficult to detect/perceive	• Poor & dated sytem design • Poor User Experience and User Interface • Replication of data • No differentiation or heirarchy • Lack of prioritization
	• Failure to scan/observe data Omission	• Time spent scanning varies for healthy / complex patients • When recognise name, bypass information gathering • Cursory look over information; can lead to mistakes
	• Distractions	• Distracted by completing notes of previous patient • Too many alerts & prompts
	• High Task Load	• Running late between consultations • Not scanning EHR; can lead to repeating a consultation
	• Misperception of data	• Cursory look over - miss important information • More time is required in information gathering
Level 2: Information Comprehension *-Interpreting Data* Failure to Comprehend Situation	• Lack of/poor mental model • Use of incorrect mental model	• Limited understanding of the patient and their medical story • Time spent scanning varies for healthy / complex patients • Quick view of the medical data entry points & frequency of visits
	Over-reliance on information	• When recognise patient/name, bypass information gathering
Level 3: Information Perception *-Anticipation of Future States* Failure to Project Situation into the Future	• Lack of/poor mental model • Over-reliance on information	• Limited understanding of the patient and their medical story • Prempt the seriousness of the consultation & approach • Multi-morbidity patients & prioritisation of conditions
Level 4: Selecting an Appropriate Action - *What Exactly Should I Do?* Failure to Select Appropriate Action for Situation	• Lack of/poor mental model • Over-reliance on information/system	• Limited understanding of the patient and their medical story • Prempt the seriousness of the consultation & approach • Multi-morbidity patients & prioritisation of conditions • EHR dominates the consultation: GPs write notes, refer to EHR
	• Management of information Memory Failure	• Complex patients/multi-morbidity • Cognitive Overload & High Task Load • Managing Multiple Goals
	Habitual Schema	• When recognise patient/name, bypass information gathering

Table 2. Situation awareness failure factors: characteristics of barriers to SA in primary care & implications.

Level of SA/ SA Error	Failure Factors	Characteristics of Barriers to SA	Implications
Level 1: Information Perception	• Data not available	• Delays & lack of integration between healthcare providers	• Better integrate data and diagnoses across healthcare providers
- *Gathering Data* Failure to Correctly Perceive Situation		• Running late between consultations	• Access key information/summary pre-consultation
		• Inconsistency in coding - missing/inaccessible data	• More consistent, comprehensive and complete coding
		• Patients not knowing their medical history/consultations	• Clinical summary is really important for the initial dialogue
		• Patients fearful of past medical problem, so don't mention it	• Build & enhance trust between GP-Patient-System
		• Variation in demographics and thus language barriers	• Information communication to transcend language barriers
		• Some patients don't consult regularly	• Holistic summaries are needed to provide context
	• Data difficult to detect/perceive	• Poor & dated sytem design	• Proposing a system that is intuitive and accessible in its design
		• Poor User Experience and User Interface	• Design should consider User Interface & where features are placed
		• Replication of data	• Differentiation in coding between diagnoses & symptoms
		• No differentiation or heirarchy	• Hierarchy in coding & in communication of information
		• Lack of prioritization	• Hierarchy and Familiarity; clear and easy to use
	• Failure to scan/observe data Omission	• Time spent scanning varies for healthy / complex patients	• Access key information/summary regardless of stratification
		• When recognise name, bypass information gathering	• Information becoming aid memore to validate assumptions
		• Cursory look over information; can lead to mistakes	• Key information interpreted at a glanceâŁ™ (up to 30s)
	• Distractions	• Distracted by completing notes of previous patient	• Information has to be interpreted âŁ˜at a glanceâŁ™ (up to 30s)
		• Too many alerts & prompts	• Prioritisation of alerts
	• High Task Load	• Running late between consultations	• Access key information/summary pre-consultation
		• Not scanning EHR; can lead to repeating a consultation	• Better connections and linking between certain information
	• Misperception of data	• Cursory look over - miss important information	• Key information interpreted at a glance' (up to 30s)
		• More time is required in information gathering	

Continued

Table 2. Continued.

Level of SA/ SA Error	Failure Factors	Characteristics of Barriers to SA	Implications
Level 2: Information Comprehension	• Lack of/poor mental model	• Limited understanding of the patient and their medical story	• Give GPs a holistic overview of patient they are consulting with
- ***Interpreting Data***	• Use of incorrect mental model	• Time spent scanning varies for healthy / complex patients	• Access key information/summary regardless of stratification
Failure to Comprehend Situation		• Quick view of the medical data entry points & frequency of visits	
	• Over-reliance on information	• When recognise patient/name, bypass information gathering	• Information becoming aid memore to validate assumptions
Level 3: Information Perception	• Lack of/poor mental model	• Limited understanding of the patient and their medical story	• Give GPs an idea of the type of patient they are consulting with
- ***Anticipation of Future States***	• Over-reliance on information	• Prempt the seriousness of the consultation & approach	• Holistic summaries; possibilities for patients to access their diinical info
Failure to Project Situation into the Future		• Multi-morbidity patients & prioritisation of conditions	• GP wants to see priorities and urgency of information: top 5/10 issues
Level 4: Selecting an Appropriate Action	• Lack of/poor mental model	• Limited understanding of the patient and their medical story	• Give GPs a holistic overview of patient they are consulting with
- ***What Exactly Should I Do?***	• Over-reliance on information/system	• Prempt the seriousness of the consultation & approach	• Holistic summaries; possibilities for patients to access their dinical info
Failure to Select Appropriate Action for Situation		• Multi-morbidity patients & prioritisation of conditions.	• GP wants to see priorities and urgency of information: top 5/10 issues
		• EHR dominates the consultation; GPs write notes, refer to EHR	• Most important information accessible quickly via EHR • Summary supports GP-Patient interaction
	• Management of information	• Complex patients/multi-morbidity	• Summary facilitates quick access and refresh of key information
	Memory Failure	• Cognitive Overload & High Task Load • Managing Multiple Goals	• Timely and quick access of key information
	Habitual Schema	• When recognise patient/name, bypass information gathering	• Information becoming aid memore to validate assumptions.

and clinical summary will be quicker if they are familiar with the patient and their medical history. Where there are limitations with the interface and system design, factors such as usability, coding and up-to-date information can also make it *difficult to perceive information* and become barriers in gaining and assimilating patient information and thus impacting the quality of information and situation awareness of the GP in scope of the consultation. Where patient information is available, the organisation and presentation of the information can make it *difficult to scan,* contextualise and make links between patterns in longitudinal data. Poor coding practice and *information incorrectly entered* also impacts the ability for GPs to ascertain and assimilate the required patient information. *High task loads* and *distractions* such as system alerts and notifications can also contribute to *misperception of data* where information is overlooked and missed, resulting in perhaps repeating consultations and possibly *memory failure*, where important patient information was initially assimilated and links between data made but then forgotten "Situation awareness often involves keeping information about a large number of factors in memory." [Endsley, 2995].

Level 2– Failure to Comprehend the Situation

In comprehending the current situation, **interpreting the patient's information** is an important part in gaining and enhancing the situation awareness when going into the consultation. GPs form a *mental model* of the patient from the information gathered, to get an "idea" and "sense" of the patient they are consulting with. This also enables the clinician to stratify a patient, so that they know if it is a "straight forward" or "complex patient". However, the limitations in the gathering of patient data can also result in the forming of an *incorrect, or poor mental model* in relation to the interpretation of patient information. Depending on the time constraints, these factors may be elicited or not, and can impact the nature of the consultation - reducing the limited 10–12 minute GP-patient time if they then have to further scan the EHR to gather patient data. Similarly, *over reliance* on prior knowledge of consultations when recognising a patient name or photo, or reliance on default data from the EHR can be problematic due to the nature of current healthcare systems, including poorly organised and fragmented information, inconsistent coding practices, and a lack of sharing between healthcare providers. These factors can contribute to errors and delays in subsequent diagnosis, treatment, care and management of conditions and diseases.

Level 3– Failure to Project Situation Into the Future

The GPs ability to project what can happen in the future (anticipation of future states) is facilitated through information acquired before and during the consultation. This enables the **forecasting of future events** and allows the GP to begin to draw connections between the disparate and diverse data, i.e., medical history, medications, previous consultations, problems they are coming in with. A *poor model* for projecting what can happen in the future would negatively affect the GPs situation awareness. Thus, the GP will go into the consultation with a limited understanding of the patient and their

medical story. This is heightened and compounded with any shortcomings in the previous stages, information gathering and information interpretation. If the GP *over-relies on information* that is inaccurate and/or incomplete; or incorrectly forecasts the nature or seriousness of the consultation, or causes of action, they will be insufficiently prepared to forecast future events and states. In an increasing ageing population with multi-morbidity, the prioritisation of conditions can differ between the medical perspective and patient needs. This would become apparent when talking to the patient and subsequently requires referring back to the EHR.

Level 4– Failure to Select an Appropriate Action

Towards **selecting an appropriate action,** the GP typically makes connections between the interpreted information in the first three levels of SA, alongside dialogue with the patient to understand their presented problem/s and priorities. The failure factors stipulated in SA Level 3, *poor mental model* and *over reliance on information* also negatively affects SA here. Thereupon, the GP may be fully cognizant of the information and aware of what is going on but has a poor mental model for projecting what it means for the future, in the management of a condition or treatment; or the actioning of the plan. Thus, this at times may result in an *over reliance* on the EHR system within the consultation, to recheck information. Likewise, when *managing complexity,* if the GP did not get a holistic overview of the patient prior to the consultation, or assumed they knew the patient, there is reduced SA, and a likelihood of missing critical information and making mistakes.

Memory failure can negatively affect Situation Awareness across the SA levels (Patel et al. 2020, Endsley 1995). Forgetting key patient information or links between data, which is heightened with the disparate and fragmented organisation of information can contribute to errors. Furthermore, *over reliance* on previous association and employing a *habitual schema,* i.e., working automatically from prior knowledge of consultations with the patient, where the EHR is not investigated with the same rigor as it would have been for patients the GP has not recently seen can also contribute to errors in situation awareness.

DISCUSSION

In this study we propose a systematic approach towards classifying SA failure factors for each SA level. The emerging taxonomy highlights the SA Failure Factors in Primary Care (*see* Table 1). The resulting taxonomy identifies improvement opportunities at individual and system levels, guiding the discussion of design implications towards enhancing SA in Primary Care (*see* Table 2). The findings reiterate that gaining and maintaining situation awareness before and during the clinical consultation is challenging for GPs. Our analysis highlights that a holistic/integrated visualisation could improve SA in all 4 SA levels.

In **SA Level 1,** perception of the current situation, GPs scan the EHR and clinical summaries to **gather patient data.** However, at times, important patient information may be unavailable, or perhaps difficult to ascertain,

assimilate or perceive. Where there is *unavailability of data,* there is a need to better integrate and share data across healthcare providers and provide effective, complete, consistent and comprehensive communication for both GPs and patients. Patients may not report on consultations, from not remembering, out of fear, or due to language barriers, negatively impacting the GPs SA and completeness of data in the EHR. Thus, a holistic clinical summary or overview can be important for the initial dialogue between GP and patient, also providing and building trust and reassurance in the service and system. GPs can run into a consultation 'blind', without any information due to time constraints. Being able to access key information and summaries prior to the consultation is extremely beneficial, providing holistic overviews and context to data spanning time, events and multiple conditions. Systemic issues in the design and usability of current systems provide *difficulty in detecting and perceiving information*. Here there is an opportunity to present information that is accessible, intuitive, prioritising key information through application of established design principles promoting hierarchy and organisation of elements. GPs may *fail at times to scan and observe data* due to factors including distractions in the environment or system, high task and cognitive load, or the *misperception of information* due to familiarity with a patient, or assumptions with data. These SA failure factors can be overcome by ensuring key information is accessible, concise, efficient and timely whilst capturing connections and patterns between data points and supporting the validation of pre-conceived assumptions.

In **SA Level 2**, comprehending the current situation, **interpreting the patient's information** is integral to enhancing the situation awareness going into the consultation. GPs assimilate information and form a *mental model* of the patient from information gathered to get an "idea" and "sense" of the patient they are consulting with, and to stratify a patient. Here, an *incorrect, or poor mental model* from incorrect projections and assumptions, *over reliance* on information and limitations at Level 1, would negatively impact SA and reduce the limited 10–12 minute consultation time with the need for further data gathering. It is important that GPs have a holistic overview of the patient they are consulting with, and able to access the key information regardless of any projected stratification, through an organised presentation of information and a clear interface and system.

In **SA Level 3**, the GPs ability to project what can happen in the future (anticipation of future states) is aided by information ascertained prior to and during the consultation. This enables the **forecasting of future events.** The GP begins to draw connections between the disparate and diverse data, i.e., medical history, medications, previous consultations, problems, there is an opportunity to illustrate and bring the connections to the forefront, reducing the cognitive load. Again, a *poor model* from incorrect projections and assumptions, *over reliance* on information and limitations at SA Levels 1 & 2, negatively impacts SA and the GP will be insufficiently prepared to forecast future events and states. SA for the Primary Care clinician can be enhanced by giving GPs an idea of the type of patient they are consulting with through a clinical summary or holistic overview, which perhaps provides an

opportunity for the GP to prioritise the urgency of information for patients with multi-morbidity and multiple medical needs.

In **SA Level 4,** as the GP **selects an appropriate action** for the consultation, deficiency in the first three SA levels can increase the likelihood of missing critical information and making mistakes. If the GP must refer back to the EHR to regather information or change course of action after conversing with the patient, then a holistic overview of the patient can support a quick presentation/refresh of necessary information. In *managing complexity* of an increasing landscape of aging and multimorbidity patients, a concise and quick presentation of ongoing conditions can help highlight the priorities and urgencies. This too can be used as an aid in the GP-Patient dialogue, towards agenda setting for the time-limited consultation.

Memory failure was flagged to negatively affect Situation Awareness across all three levels. A high task and cognitive load can augment errors, and it is possible that important patient information is initially assimilated but then forgotten. Visual representations of information are proven to be more engaging, effective and memorable than non-visual alternatives; textual or verbatim (Murray et al. 2017; Scott et al. 2017; Dur, 2014; Borkin et al. 2013, Borgo et al. 2012; Hullman et al. 2011). Holistic overviews supporting quick, efficient and effective communication of key information may become a point of reference for the GP to quickly review if information is 'lost' or 'forgotten' and can also serve as a 'prompt' or 'aide memoire' to validate assumptions in situations where habitual schemas are employed.

The results from the emerging SA failure factors taxonomy supports the need to enhance Situation Awareness prior to the GP-patient consultation. At a system level, there is a need to enhance the design and usability of the EHR, with more accessible, intuitive systems, and improved solutions to support GP tasks and practices, including both coding and assimilation of information. To provide a richer and accurate medical story of the patient, better integration and sharing of data is required between healthcare providers and systems. These considerations can contribute towards a more complete and comprehensive data set, via more accessible, intuitive interfaces, with the potential of enhancing the Primary Care clinicians' situation awareness.

Whilst the goal of EHR systems in Primary Care is to provide and convey accessible, comprehensive, timely, and accurate communication of patient information, visualizations are promising avenues to address some of the GPs situation awareness needs and barriers, potentially supporting clinicians in making more accurate and rapid decisions (Patel et al. 2020; Savoy et al. 2021). It is established that visualisations aid in improving the accessibility of information, can facilitate universal understanding through traversing language barriers, offer efficiency in the processing and decoding of information, and enable the audience to identify, understand and remember relationships and patterns (Boehnert, 2016; Cleveland, 1994). Thus, visualisations can be a great way to overcome the identified SA barriers to communicate information quickly, in the time constraint working environment of Primary Care, providing GPs with holistic visualised summaries that captures patterns and connections between data, supporting and validating assumptions or information assimilation. *Holistic overviews* and *summaries* offers the

opportunity to capture and communicate longitudinal history and stories of a patient, helping enhance the clinician's understanding of the patient, helping clinicians cope with information overload (Huang et al. 2009; Card et al. 1999), enhancing efficiency and situation awareness, thus consequently providing healthcare practitioners with essential information to provide timely interventions and advice.

CONCLUSION

Gaining SA in primary care before and during the clinical consultation is challenging and augmented with an increasing ageing population and patients with multimorbidity. This paper provides a discussion into SA, utilising interviews with GPs and Endsley's SA error taxonomy as a conceptual framework to develop and propose a systematic approach in classifying SA failure factors for each SA level. The emerging taxonomy, unique to primary care, highlights SA failure factors in primary care, and the identification of SA improvement opportunities at individual and system levels. The discussion and implications support the potential of holistic visualisations to enhance situation awareness before and during the clinical consultation through accessible, comprehensive, timely, and accurate communication of patient information in EHR. The taxonomy further flags the potential of supporting other interventions that can enhance SA, including the redesign of EHRs, a tool to support GP-Patient dialogue and the implementation of visualisation in personalised health.

REFERENCES

Aaronson EL, Quinn GR, Wong CI, Petty CR, Einbinder J, Schiff GD. (2019). "Missed diagnosis of cancer in primary care: Insights from malpractice claims data." J Healthc Risk Manag 2019; 39:19.

Baron RJ. (2007). Quality improvement with an electronic health record: achievable, but not automatic. Ann Intern Med 2007. October 16;147(8): 549–52.

Beasley JW, Wetterneck, TB, Temte J, Lapin JA, Smith P, Rivera-Rodriguez AJ, & Karsh B-T. (2011). "Information chaos in primary care: implications for physician performance and patient safety." Journal of the American Board of Family Medicine, 2011. 24(6), 745–751.

Beasley, JW., Holden, RJ., Ötleş, E., Green, LA., Steege, LM., Wetterneck, TB. (2020). It's time to bring human factors to primary care policy and practice. Applied Ergonomics, 85, 103077.

Boehnert, J. (2016). Data Visualisation Does Political Things. In Proceedings to DRS2016, Design+Research+Society: Future Focused Thinking. Brighton, UK, June 2016.

Borgo, R., Abdul-Rahman, A., Mohamed, F., Grant, PW., Reppa, I., Floridi. L., & Chen, M. (2012). An Empirical Study on Using Visual Embellishments in Visualization. IEEE Transactions on Visualization and Computer Graphics, Vol 18, No. 12, December 2012.

Borkin, MA., Vo, AA., Bylinkskii, Z., Isola, P., Sunkavalli, S., Oliva, A., & Pfister, H. (2013). What Makes a Visualization Memorable? IEEE Transactions on Visualization and Computer Graphics, Vol. 19, No. 12, December 2013.

Brady, Patrick W., et al. "Improving Situation Awareness to Reduce Unrecognized Clinical Deterioration and Serious Safety Events." Pediatrics /, vol. 131, no. 1, American Academy of Pediatrics, 2013, pp. e298–e308.

Bridgwood B, Lager KE, Mistri AK, Khunti K, Wilson AD, Modi P. "Interventions for improving modifiable risk factor control in the secondary prevention of stroke." Cochrane Database of Systematic Reviews. 2018(5).

Bui AAT & Hsu W. (2010). "Chapter 4 - Medical data visualization: toward integrated clinical workstations." In Bui, A. A. T., & Taira, R. K. (eds.), Medical Imaging Informatics. Springer Science + Business Media, LLC.

Card, S., Mackinlay, J., & Shneiderman, B. (1999). Readings in Information Visualization: Using Vision to Think. San Francisco: Morgan Kaufmann Publishers.

Chana NS, Porat T, Whittlesea C, Delaney BC. "Improving specialist drug prescribing in primary care using task and error analysis." British Journal of General Practice (BJGP), 2017.

Cleveland WS. (1994). The Elements of Graphing Data, Revised Edition. Hobart Press, New Jersey.

Despins LA. Advancing Situation Awareness Research. Western Journal of Nursing Research. 2018;40(3): 303–304.

Drews FA. & Westenskow, D. R. "The Right Picture is Worth A Thousand Numbers: Data Displays In Anesthesia." Human Factors 2006; 48 (1): 59–71.

Dur BIU. (2014). Data Visualization and Infographics In Visual Communication Design Education At The Age of Information. Journal of Arts and Humanities, 3(5), 39–50.

Eghdam A, Forsman J, Falkenhav M, Lind M, Koch S. "Combining usability testing with eye-tracking technology: evaluation of a visualization support for antibiotic use in intensive care." Stud Health Technol Inform 2011;169:945–9.

Elo S, Kyngäs H. "The qualitative content analysis process." J. Adv. Nurs., 2008. 62 (1), 107e115.

Endsley MR. "A taxonomy of Situation Awareness Errors." In: Fuller R, Johnston N, McDonald N, editors. Human Factors in Aviation Operations. Aldershot: Ashgate Publishing, 1995. p. 287–92.

Endsley MR. Design and Evaluation for Situation Awareness Enhancement. Proceedings of the Human Factors Society Annual Meeting. 1988;32(2): 97–101.

Evans RS. (2016). Electronic Health Records: Then, Now, and in the Future. Yearbook of medical informatics, Suppl 1(Suppl 1), S48–S61. https://doi.org/10.15265/IYS-2016-s006

Furlow B. "Information overload and unsustainable workloads in the era of electronic health records." The Lancet Respiratory Medicine, Online First, 2020. Available at: https://www.thelancet.com/journals/lanres/article/PIIS2213-2600(20) 30010-2/fulltext [Accessed 03 Feb. 2020].

Graber ML, Byrne C, & Johnston D. (2017). "The impact of electronic health records on diagnosis." Diagnosis, 4(4), 211–223.

Howe JL, Adams KT, Hettinger AZ, Ratwani RM. (2018). Electronic health record usability issues and potential contribution to patient harm. JAMA, 319, 1276–1278.

Huang W, Eades P, & Hong SH. (2009). Measuring Effectiveness of Graph Visualizations: A Cognitive Load Perspective. Information Visualization, 8, 139–152.

Hullman J, Adar E, & Shah P. (2011). Benefitting InfoVis with Visual Difficulties. IEEE Transactions on Visualization and Computer Graphics, Vol. 17, No. 12, December 2011.

Kostopoulou O, Porat T, Corrigan D et al. "Diagnostic accuracy of GPs when using an early-intervention decision support system: a high-fidelity simulation." Br J Gen Pract. 2017 Mar 1;67(656): e201-8.

McCarthy G. "Situation awareness in medicine." Quality and Safety in Health Care, 2016. Vol. 15 (5), pp. 384.

McGuinness B, Foy L. A subjective measure of SA: the crew awareness rating scale (CARS). Proceedings of the First Human Performance, Situation Awareness, and Automation Conference, Savannah, Georgia, October, 2000.

Murphy DR, Giardina TD, Satterly T, Sittig DF, Singh H. (2019). An exploration of barriers, facilitators, and suggestions for improving electronic health record inbox-related usability: A qualitative analysis. JAMA Network Open, 2, e1912638.

Murray IR, Murray AD, Wordie SJ, Oliver CW, Simpson AHRW, & Haddad FS. (2017). What Surgeons Need to Know About Infographics. The Bone & Joint Journal, 99-B: 1557–1558.

Pashaei V, Gross DC. "Toward an integrated Situational Awareness measuring function for Electronic Health Records." In: Stephanidis C. (eds) HCI International 2019 - Posters. HCII 2019. Communications in Computer and Information Science, 2019. vol 1034. Springer, Cham.

Patel AM, Porat, T, and Baxter WL. (2020) "Enhancing Situation Awareness and Decision Making in Primary Care: Clinicians' Views," 2020 IEEE International Conference on Healthcare Informatics (ICHI), 2020, pp. 1–9.

Peeck J. "Increasing Picture Effects in Learning from Illustrated Text." Learning and Instruction, 1993. Vol. 3, pp. 227–238.

Porat T, Delaney B, Kostopoulou O. "The impact of a diagnostic decision support system on the consultation: perceptions of GPs and patients." BMC medical informatics and decision making, 2017 Dec;17(1):79.

Porat T, Kostopoulou O, Woolley A, Delaney BC. "Eliciting user decision requirements for designing computerized diagnostic support for family physicians." Journal of Cognitive Engineering and Decision Making, 2016. vol. 10 (1), pp. 57–73.

Porat T, Marshall IJ, Sadler E et al. "Collaborative design of a decision aid for stroke survivors with multimorbidity: a qualitative study in the UK engaging key stakeholders." BMJ open 2019; 9(8): e030385.

Powell L, Sittig DF, Chrouser K, Singh H. (2020). Assessment of health information technology–related outpatient diagnostic delays in the US Veterans Affairs health care system: A qualitative study of aggregated root cause analysis data. JAMA Network Open, 3, e206752.

Prasad A. (2016). "How to tame the EHR to conquer information overload." [online] The Doctor Weighs In. Available at: https://thedoctorweighsin.com/how-to-tame-the-ehr-to-conquer-information-overload/ [Accessed 20 Jan. 2020]. Singh H. Diagnostic errors: moving beyond 'no respect' and getting ready for prime time. BMJ Quality & Safety 2013;22: 789–792.

Ramnarayan P, Kapoor RR, Coren M, Nanduri V, Tomlinson AL, Taylor PM, Wyatt JC, Britto JF. "Measuring the impact of diagnostic decision support on the quality of clinical decision making: development of a reliable and valid composite score." J Am Med Inform Assoc. 2003;10(6):563–72.

Rand V, Coleman C, Park R, Karar A, Khairat S. "Towards understanding the impact of EHR-related information overload on provider cognition." Studies in Health Technology and Informatics, 2018. 251, 277–280.

RCGP – Royal College of General Practitioners. "Responding to the Needs of Patients with Multimorbidity: A Vision for General Practice." Royal College of General Practitioners, 2016.

Roman LC, Ancker JS, Johnson SB, Senathirajah Y. (2017). Navigation in the electronic health record: A review of the safety and usability literature. Journal of Biomedical Informatics, 67, 69–79.

Salmon PM, Stanton NA, Walker GH, Baber C, Jenkins DP, McMaster R, & Young MS. What really is going on? Review of situation awareness models for individuals and teams. Theoretical Issues in Ergonomics Science, 2009. 9(4), 297–323.

Savoy A, Patel H, Murphy DR, Meyer AND, Herout J, Singh H. Electronic Health Records' Support for Primary Care Physicians' Situation Awareness: A Metanarrative Review. Human Factors. May 2021.

Schulz CM, Krautheim V, Hackemann A, Kreuzer M, Kochs EF, Wagner KJ. "Situation awareness errors in anesthesia and critical care in 200 cases of a critical incident reporting system." BMC Anesthesiol. 2016. 16(1):4.

Scott H, Fawkner S, Oliver C, & Murray A. (2017). How to make an engaging infographic?British Journal of Sports Medicine. 51. 1183–1184.

Singh H, Giardina TD, Petersen LA, Smith MW, Paul LW, Dismukes K, Bhagwath G, Thomas EJ. "Exploring situational awareness in diagnostic errors in primary care." BMJ Qual Saf. 2012;21(1):30–8.

Singh H, Petersen LA, Thomas EJ. (2006). Understanding diagnostic errors in medicine: A lesson from aviation. Quality and Safety in Health Care, 15, 159–164.

Sinsky CA, Beasley JW, Simmons GE, Baron RJ. (2014). Electronic health records: Design, implementation, and policy for higher-value primary care. Annals of Internal Medicine, 160, 727–728.

Stubbings L, Chaboyer W, & McMurray A. (2012). Nurses' use of situation awareness in decision-making: an integrative review. Journal of advanced nursing, 2012. 68(7), 1443–1453.

Temte JL, Beasley JW, Holden RJ, Karsh BT, Potter B, Smith P, O'Halloran P. (2020). Relationship between number of health problems addressed during a primary care patient visit and clinician workload. Applied Ergonomics, 84, 103035.

Tory M, Moller T. (2004). Human factors in visualization research. IEEE transactions on visualization and computer graphics. 2004 Jun 14; 10(1): 72–84.

Waller RG, Wright MC, Segall N, Nesbitt P, Reese T, Borbolla D, & Del Fiol G. "Novel displays of patient information in critical care settings: a systematic review." Journal of the American Medical Informatics Association, 2019. 26(5), 479–489.

Wenzl M. (2019). "New ways of delivering care for better outcomes." Health in the 21st Century: Putting Data to Work for Stronger Health Systems, OECD Health Policy Studies, OECD Publishing, Paris.