SPECIAL ARTICLES

Application of the Haddon matrix to COVID-19 prevention and containment in nursing homes

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Abstract

COVID-19 has exacted a disproportionate toll on the health of persons living in nursing homes. Healthcare providers and other decision-makers in those settings must refer to multiple evolving sources of guidance to coordinate care delivery in such a way as to minimize the introduction and spread of the causal virus, SARS-CoV-2. It is essential that guidance be presented in an accessible and usable format to facilitate its translation into evidence-based best practice. In this article, we propose the Haddon matrix as a tool well-suited to this task. The Haddon matrix is a conceptual model that organizes influencing factors into pre-event, event, and post-event phases, and into host, agent, and environment domains akin to the components of the epidemiologic triad. The Haddon matrix has previously been applied to topics relevant to the care of older persons, such as fall prevention, as well as to pandemic planning and response. Presented here is a novel application of the Haddon matrix to pandemic response in nursing homes, with practical applications for nursing home decision-makers in their efforts to prevent and contain COVID-19.

KEYWORDS
COVID-19, Haddon matrix, long-term care, nursing home

INTRODUCTION

As the United States' efforts to contain Coronavirus Disease 2019 (COVID-19) are challenged by record-breaking surges in incidence, it is increasingly important that lessons learned throughout the response inform practice. SARS-CoV-2 has infected millions of Americans and taken the lives of hundreds of thousands.[1] Less than 3% of those cases have been among persons living in nursing homes, but more than 25% of the country's deaths from COVID-19 have occurred among this group.[1,2]

The disproportionate burden being shouldered by persons living in nursing homes highlights the importance of healthcare personnel and facility decision-makers operating in accordance with best-practice guidelines in those settings. The availability of such guidelines has greatly increased over time, as evidenced by the expansion of the U.S. Centers for Disease Control and Prevention's (CDC's) COVID-19 guidance for nursing homes from a single website published in early 2020, to half a dozen or more.[3] Indeed, individual nursing homes report using up to five different COVID-19 guidance documents on average.[4]

As this growth of available guidance continues, so too will the importance that findings and recommendations are presented in an accessible and usable format, else important points are at risk of being lost in an overwhelming tide of information. For example, a search in PubMed for literature on COVID-19 in long-term care facilities (LTCFs) retrieves more than 330 publications, yet less than 50 address the application of theoretical or organizational models, or speak to the reproducibility, feasibility, or scalability of their findings (search concepts available in Appendix S1). Indeed, multiple publications that seek to compile important recommendations for nursing homes lack focus on these implementation considerations.[5,6] This presents a need for a systematic, analytic framework that organizes and presents guidance on relevant areas for intervention and control. One such framework is the Haddon matrix.[7]

The Haddon matrix was developed by Dr. William Haddon, Jr. in 1968 to address a similar lack of an analytic approach in the field of injury prevention and response.[7] Haddon appreciated that rather than analyzing etiologic factors associated with injuries and their sequelae, which might have allowed for identification of ways to modify them, injuries were being attributed to misfortune. Haddon's response to this phenomenon was the development of a matrix, constructed by organizing "influencing factors," or variables affecting the outcome of interest. As depicted in Figure 1, these influencing factors are arranged according to whether they exert their influence during the pre-event, event, or post-event phase and whether they fall into the host, agent, physical
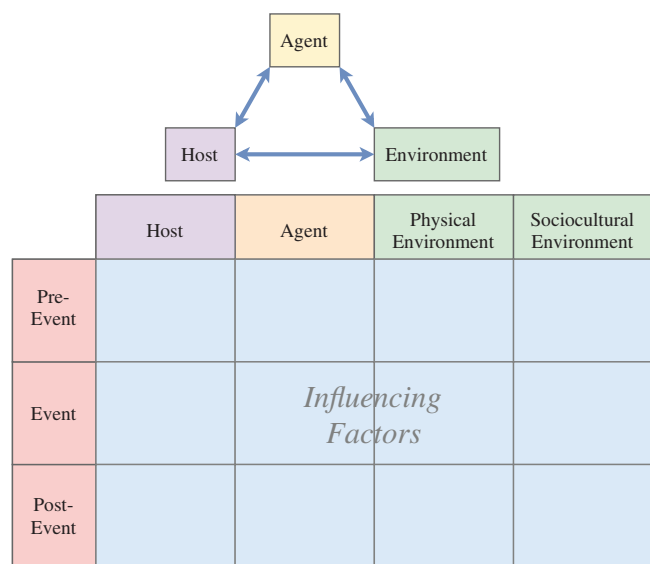

FIGURE 1 The Haddon matrix is shown here with the components of the epidemiologic triad corresponding to the matrix's four columns or domains

Key Points

- Recommendations for COVID-19 response in nursing homes are vast and evolving.
- The Haddon matrix is a concise structure in which these recommendations can be organized.

Why Does this Paper Matter?

This paper presents a novel application of the Haddon matrix, highlighting its utility in COVID-19 response in nursing homes.

environment, or sociocultural environment domain. Both the phases and domains are defined during the construction of the matrix in accordance with the subject or problem to which the matrix is being applied. Although this model was initially developed for use in injury prevention, it has since been applied to a broad array of public health challenges, including to the care of older persons; for example, the Haddon matrix has been applied to topics ranging from fall prevention[8] to quality improvement in residential respite care.[9] In nursing homes, similar phased approaches have been used to contextualize the role that nursing facilities play in their communities during disasters such as earthquakes.[10] The matrix presented here, shown in Table 1, is not intended to be definitive, but rather, adapted or modified to an appropriate fit in accordance with facility-specific factors. This article examines a novel application of the Haddon matrix to pandemic planning and response considerations for nursing homes, with a specific focus on practical applications for COVID-19.

METHODS

At the time of this writing, application of the Haddon matrix to pandemic planning and response in nursing homes or other long-term care settings, including for COVID-19, has not yet been reported in the literature. As such, the approach to identifying influencing factors to populate the Haddon matrix described here involved a combination of three complementary strategies.

The first strategy included a review of COVID-19-specific guidance published by CDC,[11–17] as well as guidance pertaining to nursing home prevention and containment of COVID-19 published by the Centers for Medicare & Medicaid Services (CMS).[18] The second pulled influencing factors from the Haddon matrix

TABLE 1 Haddon matrix applied to COVID-19 prevention and containment in nursing homes

| Phase | Influencing factors | | | |
	Host	**Agent**	**Physical environment**	**Sociocultural environment**
Pre-event	**Staff competency in IPC measures**	Disease virulence	**Availability of quarantine and isolation beds**	**IPC Program leadership and compliance auditing**
	Pre-event education/risk communication	Infectivity	**Environmental cleaning and disinfection**	**Punitive vs nonpunitive illness exclusion policy**
	Rate of introduction of new residents[a]	Incubation period	**Availability of hand hygiene supplies**	**Visitor restriction policies**
	Staff working in other healthcare facilities		Availability of COVID-19 vaccine	**Policies for screening upon entrance**
	Pre-event staff and resident immunity		**Surveillance testing strategy and supply**	**Structured pre-event planning processes**
			PPE supply and use	**External partnerships (other facilities, public health)**
			Level of community transmission	**Information exchange policies and capacity**
Event	**Staff competency in IPC measures**	Environmental persistence of SARS-Cov-2	**Physical distancing and status of congregate areas**	**Compassionate care visitation policies**
	Pre-event staff and resident immunity	Infectivity	**Persistence of staff assignments or staff floating**	**Policies to address staffing shortages**
	Case mix of higher-risk and memory care residents	Incubation period	**Timing, breadth, and frequency of response testing**	**External partnerships (other facilities, public health)**
		Disease virulence	**Availability of quarantine and isolation beds for cohorting**	**IPC Program leadership and compliance auditing**
			Availability of hand hygiene supplies	**Information exchange policies and capacity**
			Density of populated units[a]	
			PPE supply and use	
			External/alternate care sites	
			Environmental cleaning and disinfection	
Post-event	**Staff competency in IPC measures**	Environmental persistence of SARS-Cov-2	**Breadth and frequency of testing**	**Compassionate care visitation policies**
	Proportion of staff and residents recovered and immune		**Availability of hand hygiene supplies**	**IPC Program leadership and compliance auditing**
	Duration of protective immunity		**Environmental cleaning and disinfection**	**Structured post-event evaluation processes**
			Availability of COVID-19 vaccine	**Information exchange policies and capacity**
			PPE supply and use	

Note: Haddon matrix populated with influencing factors specific to COVID-19 containment in nursing homes. Bolded influencing factors are potentially able to be modified by nursing home administrators or personnel.

Abbreviations: IPC, infection prevention and control; PPE, personal protective equipment.

[a]Nursing home may have the ability to change with deviation from standard practice or services offered.

publications in PubMed that applied a relatively unmodified matrix to infectious disease challenges.[19–23] The final step involved review of select publications in the literature on COVID-19 in nursing homes, including the Morbidity and Mortality Weekly Report (MMWR) article describing the first COVID-19 outbreak in a nursing home in the United States,[24] as well as three more recent publications focused on this setting.[25–27] These strategies yielded a set of evidence-based influencing factors, abstracted from publications, that were amalgamated to populate the matrix detailed in Table 1. The relationship between each influencing factor included in the Haddon matrix presented in this article and the references identified in the literature can be found in Appendix S1.

As mentioned above, the matrix is structured according to the phases of response. The "event" phase is defined in the matrix presented here as the introduction of COVID-19 into a nursing home. During the pre-event phase, the facility has not yet identified a case. During the post-event phase, containment measures have been implemented and transmission has been interrupted. A threshold for progression to the post-event phase (i.e., outbreak resolution definition) can be defined by the facility, or by criteria provided to the facility by its public health partners (e.g., local/state health departments and federal public health agencies). This may not require the illness and infectiousness of all cases to be entirely resolved, but likely will require a sufficient period of time to have elapsed for the facility to be confident that there is no illness incubating among the negative cohort. In the matrix presented in Table 1, influencing factors that can be controlled by nursing home administration or personnel appear in bolded font, to indicate potential targets for intervention.

RESULTS

There were 31 unique influencing factors abstracted from the literature. These influencing factors include infection prevention and control (IPC) measures common to many infectious diseases, such as effective hand hygiene and exclusion of sick personnel. They also include interventions that have become routine in long-term care facilities as part of the response to COVID-19, such as broad surveillance testing of staff. Some of these factors are represented more than once in the Haddon matrix presented in Table 1, as they describe interventions relevant to more than one phase. For example, PPE supply and employment is relevant to both keeping COVID-19 out of a facility as well as responding after introduction. As

such, that factor is present in the pre-event, event, and post-event phases. There were 25 such instances of recurrence of a factor in an identical or nearly identical form within a single domain, which, combined with the 31 unique influencing factors, result in the 56 factors presented in Table 1. Most of the identified influencing factors (84%) were supported by at least two publications, with an average of 3.3 publications per factor. There was little to no divergence between the CDC and CMS guidance and the peer-reviewed literature regarding relevant influencing factors. These factors were organized into the three rows and four columns of the matrix corresponding to their pre-event, event, or post-event phase designations (rows) and their specificity to the host, agent, physical environment, or sociocultural environment domains (columns). Organized in this manner, these factors constitute the Haddon matrix shown in Table 1. The 40 influencing factors that might be controlled by facility-level decision-makers are indicated in bold font. There were no such bolded factors in the agent domain, as staff in nursing homes will not likely be able to alter the characteristics of the SARS-CoV-2 virus directly.

Examination of these factors highlights the priorities in each phase.[19] For example, pre-event availability of personal protective equipment (PPE) might allow for the universal masking policy that achieves that phase goal of *preventing introduction*. In the event phase, PPE availability might allow for effective transmission-based precautions to be employed, *preventing intrafacility spread*. Finally, in the post-event phase, availability of PPE and structured post-event evaluation processes might both relate to the need for a comprehensive reassessment of PPE supplies to determine whether sufficient materials remain to *safely resume functions while minimizing harm from any longer-term sequelae*. This examination of a single influencing factor brings focus to the relationship between the matrix's three phases and how the priorities in each phase inform each influencing factor included in Table 1.

DISCUSSION

The application of the Haddon matrix to the prevention and containment of COVID-19 in nursing homes, as shown in Table 1, is novel. The existing literature based on the Haddon matrix describes the utility of this tool in pandemic response but not in the context of nursing homes or other long-term care facilities. The application described here builds on the existing literature, both by placing it in the nursing home context and through practical application to the prevention and containment of COVID-19.

The emergence of the COVID-19 crisis in LTCFs has been met with an abundance of related guidance. This body of recommendations might be even more beneficial if organized in such a way as to maintain accessibility, relevance, and flexibility for adaptation to varied practice settings. The Haddon matrix is presented here for its ability to meet that organizational need with a concise structure that is systematic and scalable. The domains into which influencing factors are organized align well with the three domains present in the epidemiologic triad of host, agent, and environment. This framework is familiar to healthcare providers, facilitating acceptance and application. The expansion of the environment domain from that framework into the physical environment and sociocultural environment domains in the Haddon matrix, while adding a layer of complexity, is better suited for use by facility decision-makers.

One potential application to practice is the employment of this matrix as a brainstorming tool at the facility-level. Decision-makers and representative stakeholders, such as facility administrators and direct-care personnel, can identify influencing factors specific to their own experience to construct and tailor the contents of a Haddon matrix unique to their facility. This process demonstrates the adaptability of this tool, as the inclusion, exclusion, and bolding of factors that are under the control of facility decision-makers will vary as the tool is adapted to reflect differences among individual facilities. Although the most apparent application of the matrix presented here is at the facility-level, the influencing factors included are relevant to planning at the level of a health service area, regional, or national facility network, demonstrating the scalability of the Haddon matrix. The scalability of this type of phased approach to disaster planning, with consideration to host, event, and environmental factors, was demonstrated by Saliba and colleagues who used such an approach to characterize the role and function of nursing homes in their larger communities following an earthquake.[10] There is precedent for this type of employment of the Haddon matrix as a brainstorming tool in nursing homes. Although not yet applied to the type of infectious disease challenge described here, it has been used to generate interventions to reduce mortality associated with unexplained absences among persons living in nursing homes.[28] Once the Haddon matrix has been developed around a specific event, such as the introduction of COVID-19 to a nursing home, it can be updated in accordance with evolving guidance and applied as described below.

A populated Haddon matrix might be utilized in a singular or time-limited manner, similar to other preparedness resources, such as CDC's Infection Control Assessment and Response (ICAR) tool.[14] The Haddon matrix's concise presentation of influencing factors affords facility-level decision-makers the ability to quickly review areas for intervention. As an example, a nursing home administrator who has witnessed neighboring facilities struggle to contain COVID-19 might be interested in determining where additional resources can be focused to prevent introduction into their own facility. By focusing on the pre-event phase of their previously established matrix, the interventions that apply to each domain would become clear. In this case, the facility administrator might address the sociocultural environment by delegating to their infection preventionist and human resources staff the task of developing an ill employee exclusion policy that is nonpunitive and encourages personnel to answer honestly when they are screened for symptoms before shifts. Additionally, the facility administrator might identify factors in the physical environment domain that could be enhanced through the effort of their environmental services staff. For example, they might task those staff with developing a checklist of high-touch surfaces that need to be cleaned each shift and ask them to incorporate in that checklist an assessment of sanitizer dispensers to assure that their healthcare personnel can practice effective hand hygiene.

The Haddon matrix might also be utilized in an ongoing fashion by facility decision-makers in planning and resource allocation. Runyan described an approach by which principles of policy analysis could be incorporated into this process, expanding the Haddon matrix into a "third dimension."[29] This application of the Haddon matrix as a planning and decision-making tool might flow naturally from its use as a preparedness assessment instrument, following the identification of gaps. In this way, application of the matrix might augment planning occurring as part of CMS-required annual emergency program review, which now explicitly requires consideration of emerging infectious diseases as part of an all-hazards approach.[30] Alternatively, this application might *follow* a response as part of after-action or evaluation activities. The information thus afforded (i.e., lessons learned) might allow for the types of analysis of factors, from equity (e.g., equitable treatment of residents) to effectiveness, that Runyan describes.[29] Decision-makers might thereby consider the influencing factors in the event phase to refine responses in future events. For example, a facility administrator who prioritized the physical environment factor pertaining to PPE supply and dedicated significant resources to procurement might observe self-contamination during PPE doffing procedures or observation of staff lowering their masks in shared workspaces to talk on the phone. This would lead to a subsequent conclusion that the effectiveness of that intervention would have been enhanced by an additional

focus on the sociocultural environment factor of IPC program leadership and compliance auditing. In its original format, the columns of the Haddon matrix do not indicate influencing factors that are under the control of decision-makers. We have added a feature that designates such factors by presenting them in bolded font. Not only does this allow for more ready identification of factors to be addressed at the facility-level, it also makes clear the absence of such factors in the agent domain, directing focus to the host and environment domains in which facility decision-makers can exert control.

One limitation of the Haddon matrix is that it does not indicate the relationships among factors, nor differences in their relative importance or priority. One solution to this limitation, proposed by Runyan, can be realized by modifying the matrix to incorporate value criteria to aid in prioritization and decision-making.[29] Value criteria are the factors such as cost, equity, and feasibility, which must be considered by facilities in deciding upon prevention and response measures.[29] For example, a facility considering a nonpunitive illness exclusion policy might assess such an intervention favorably in terms of equity. It could mean that all staff are able to access sick leave regardless of their personal financial situation. However, that policy might constitute an increase in cost, and thus a less favorable assessment for that value criterion. Whether the facility is able to absorb that added cost might determine whether this policy is adopted or whether other pre-event influencing factors, such as a more rigorous pre-shift screening program, need to be considered. Considering value criteria is particularly important in the context of limited staff and material resources. There is precedent for employment of a Haddon matrix in this way in long-term care: such a matrix was used in the development and dissemination of recommendations to reduce harm in nursing-home-based respite care.[9] In addition, as mentioned above, a similar phased approach was used to characterize the role and function of nursing facilities in the larger context of their communities during disasters.[10] Similar follow-up studies would provide evidence to support the implementation of the methods described here.

Reflected in the results of this article (i.e., the identified influencing factors) is the fact that our understanding of SARS-CoV-2 is still growing, and so too is the list of public health interventions available to us in our response. The development of vaccines is an example of this, and further knowledge of periods of infectivity likewise affects our approach to constructing and interpreting the Haddon matrix. Depending on proportions vaccinated and the answers to complex questions about duration of immunity and ability to transmit disease, a facility might find itself in all phases of an event simultaneously. Even as outbreaks wind down, opportunities for new introduction of SARS-CoV-2 must be identified and addressed. This balance will shift over time, according to the proportion of staff and patients with protective immunity.

We have demonstrated the potential application of the Haddon matrix as a tool to aid preparedness planning and response to COVID-19 in nursing homes. It is a structured and systematic conceptual model that allows decision-makers to organize influencing factors by temporal relationship to an event and domains of interest. These factors may originate from published sources, such as those identified in our initial steps in the construction of the matrix shown in Table 1, or they may be refined at a local level to reflect unique characteristics of individual nursing homes. In the latter application, potential benefits include its use as a framework for adapting existing guidance, an assessment and brainstorming tool, a roadmap for allocating tasks and dedicating resources, and/or the evaluation and improvement of response. Its accessibility to administrators and other decision-makers provides them with a valuable instrument for preventing undue morbidity and mortality from COVID-19 in the high-risk settings of nursing homes.

CONFLICT OF INTEREST

AUTHOR CONTRIBUTIONS

All authors contributed to the conception of this manuscript, and from that starting point, shared in the writing and revision process.

SPONSOR'S ROLE

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

Appendix S1: Detail of literature search strategies and list of influencing factors included in Table 1, associated with the reference publications from which they were identified.