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Extending our Understanding of the Social Determinants of Physical Activity and Sedentary Behaviors in Families: A Systems Mapping Approach

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Abstract

Background: The social environment is important to consider for effective promotion of movement behaviors like increased physical activity (PA) and reduced sedentary behavior (SB), yet it is less often considered than individual and built environment. One way to advance social environment research is to develop system maps, an innovative participatory action-oriented research process that actively engages stakeholders to visualize system structures and explore how systems "work." The purpose of this research was to develop PA and SB system maps of the social environment embedded within the core/nuclear family system. **Methods:** The development process began with a two-day multi-country, 16-researcher, in-person participatory workshop in August 2023, followed by multiple online follow-up consultations. Attendees contributed to the creation of the maps through shared development of critical determinants and their causal pathways. The structure of the final maps was analyzed using network analysis methods to identify indicators of centrality, and key feedback loops and areas for potential intervention were explored. **Results**: Key central determinants that are likely critical targets for systems intervention to produce changes in PA and SB and featured prominently in most of the reinforcing and balancing feedback loops included shared family interests, values and priorities, family logistical support, family cohesion/organization, and shared experiences. The maps also highlighted key determinants of the broader social environment external to the family. **Conclusions:** These system maps support current evidence on movement behaviors in family systems and socioecological theories, and have the utility to galvanize future research and policy to promote PA and reduce SB.

Key Words: Social Support; Subjective Norm; Parenting Practices; Built Environment; Socioeconomic Position

Background

Two of the most consequential health behaviors impacting chronic disease are regular physical activity (PA) and sedentary behavior (SB). Specifically, regular moderate-to-vigorous intensity aerobic PA of 150 minutes per week (consisting of any voluntary movement of skeletal muscles that uses 3.0 or more metabolic equivalents, or performed at least at 64% of maximal heart rate[1]), among adults is associated with reduced likelihood of over 25 chronic health conditions,[2] improved social outcomes such as lowered loneliness and greater community connectedness [3], and environmental benefits such as lowered use of automobiles due to active transport.[4, 5] Children who engage in regular moderate-to-vigorous intensity aerobic PA for 60 minutes per day are more likely to display better body composition, cardiorespiratory and musculoskeletal fitness, academic achievement and cognition, prosocial behaviors, family function, and overall mental health.[6-10]

Similarly, SB, defined as "any waking behavior characterized by an energy expenditure ≤1.5 metabolic equivalents, while in a sitting, reclining or lying posture"[11] in excess of approximately eight hours per day among adults,[12] is associated with a range of chronic health conditions such as heart disease and type 2 diabetes, depression, lower cognitive function, lower quality of life, metabolic dysfunction, some cancers, and reduction in bone mineral density.[13-15] Children and youth who engage in lower SB are more likely to display better growth, body composition, cardiorespiratory and musculoskeletal fitness, cardiovascular and metabolic health, motor development, cognitive development, academic achievement, emotional regulation, prosocial behaviors, quality of life, and overall family functioning.[10, 16-18] Importantly, PA and SB are not mutually exclusive,[19] yet the health effects of too much SB and too little PA seem to be partly independent.[15, 20]

Despite the impressive benefits and risks of these health behaviors, many people are challenged by low PA and high SB prevalence and frequency. For example, globally, only 50% of adults and 20% of children and youth participate in regular PA at recommended guideline levels.[21, 22] Adults spend roughly 9-10 hours per day engaging in SB;[23] high childhood SB, particularly excessive screen time, is equally challenging globally.[24] Thus, taken together, it is clearly important to understand the influences of PA and SB to inform public health promotion.

The determinants of PA[25, 26] and SB[27-29] are socioecological in scope, encompassing biological/genetic, individual, social, environmental, and policy factors. While early research focused heavily on demographic and individual predictors of these behaviors,[30, 31] recent approaches have now expanded to built and natural environments,[32] and more complex psychological models.[33-36] Despite this expansion, attention to the various social processes associated with SB and PA has remained less cohesive. Specifically, while health behavior theories nearly always include a reference to social factors in health behavior, social constructs within these theories are seldom the focus.[37, 38] For example, socioecological approaches to conceptualizing health behaviors often acknowledge the importance of the social environment but have a tendency to emphasize the built and natural environment infrastructure more in their application.[32, 39, 40] Similarly, the role of social factors (e.g., perceived social support, relatedness needs) is generally presented as less nuanced than that of psychological constructs (e.g., self-efficacy, goals, and intentions).[41, 42] As demonstrated by Rhodes and Beauchamp,[38] it is common for many of these models to include a single "social influences" construct, or a list of social referents (e.g., friends, family, spouse, etc.) that may affect behavior, without the nuances of how these social factors are related and their composite interactions with health behaviors.

In light of the current limited theoretical perspectives on the role of social factors, more attention to the social environment in determining PA and SB is warranted. The **social environment** comprises the surroundings, social relationships, and cultural milieu within which people function and interact.[43] Haughton, McNeill et al.[44] expanded upon this generalized definition by providing a useful framework and taxonomy of the social environment for health behaviors such as PA and SB. Their taxonomy included five main social environment contributors: social support and social networks (presence and nature of interpersonal relationships and interactions); socioeconomic position and income inequalities (social standing in society and the unequal distribution of income); discrimination (interpersonal or institutional bias that limits opportunities); neighborhood (factors of "place" rather than the aggregation of individuals living in an area); and social cohesion and capital (connectedness and solidarity among groups and shared resources). These factors clearly indicate the scope and boundary conditions of the social environment, beginning with interpersonal factors and ending with social policy-related factors that affect health behaviors. However, although the taxonomy lists the main social environment factors, it does not specify the associations between these factors or the ways they operate together. Thus, additional research is needed to establish the connections among factors in this taxonomy.

Given the size and scope of the social environment,[44] a focus on key social systems may assist in overcoming limitations of socio-ecological models by yielding a more refined map of the social environment, including both determinants and the complex links between them, as well as the various interacting outcomes (intended or unintended) that result from efforts to increase PA and decrease SB.[45] Clearly, the promotion of PA and reduction of SB can be targeted within multiple settings, such as schools,[46] the workplace,[47] and the general

community.[48] However, many leisure-time hours are spent within the context of the family system,[49] making the nuclear/proximal family context a critical focus for promoting PA and reducing SB at a population level.[24] Family systems, which are instrumental in their impact on child development, are complex and the family unit is in a constant cycle of interactions, with evolution and behavior change being inherent.[49, 50] Further, while family membership can vary considerably, as can roles and responsibilities, core systems typically involve adult partners and/or children within the family home. Thus, a focus on the social environment of the core/nuclear family system is warranted.

To date, the focus on family PA, SB, and the social environment has been limited to taxonomies and figures that outline the purported breadth of social determinants.[51-54] As a recent example, Rhodes and colleagues[24] developed a consensus statement and conceptual model to illustrate how the family is important for the support and promotion of healthy movement behaviors among children and youth. Similarly, a recent review outlined the key factors associated with health behavior changes among dyadic couples.[53] However, these approaches are limited because, while they outline potential key social environment constructs related to PA and SB in the core family system, they neglect the interrelation of these concepts. An advancement of this prior research would include the production of system maps,[55] which often represent a participatory action-oriented research process to visualizing complex systems, advancing theory development, and identifying potential targets for public health interventions. A systems approach to PA and SB and the social environment would connect interpersonal relationships and interactions, socioeconomic factors, interpersonal or institutional biases, social elements of neighborhood and connectedness, and shared resources in terms of how they intersect within a system, accounting for their interdependence and relative strengths.

System maps have had utility in actively engaging stakeholders in domains such as the food environment and dietary behavior,[56] socio-ecological connections to obesity,[57] and the built and natural environment and individual factors related to PA within a city.[58] Attempts have also been made to create global representations of PA systems.[59, 60] The participatory approach involves a group of stakeholders to explore what a system looks like and how it "works" by using a structured, step-by-step format to create a map of elements in a system and the links between these, which in some forms can then be used to explore dynamics in the network (e.g. proposed causal loops diagrams). Subsequently, system maps may help inform responses to complex issues through a participatory research approach, which harnesses domain-specific expertise or important knowledge about certain aspects of the system.[61, 62]

Thus, to inform theory development, action, and a research agenda, the purpose of this research was to develop two system maps of key social environment determinants embedded within the core/nuclear family system (e.g., children, youth, and adults): one for meeting international PA guidelines[63] and the other for restricting SB using the Canadian guidelines.[12] Specifically, we describe the development process of these maps over a two-day participatory workshop (map building) and several subsequent online consultations among attendees (map refinement and validation), and discuss the results in terms of how these system maps can subsequently help inform attempts to identify potential intervention points to promote the "system" behaviors of increased PA and reduced SB for families.

Methods

Design

Sixteen researchers with expertise relating to PA, SB, family systems, the social environment, and systems mapping from nine countries (Austria, Belgium, Canada, Germany,

Ireland, Poland, Slovakia, Switzerland, and the UK), who were attendees of the 37th Annual Meeting of the European Health Psychology Society, met for a two-day pre-conference workshop (Synergy Expert Meeting) in Bremen, Germany on the 3rd and 4th of September 2023. Attendees held expertise in different psychology specialisations (e.g. clinical, cognitive, individual, critical, social, environmental and health) and sports science.

The two sessions (day 1: PA; day 2: SB) were facilitated by two experienced researchers (RR, AL) who took turns introducing the daily sessions and managing the activities. Two research assistants (ZS, AB) trained in the use of systems mapping software (Systems Thinking In Community Knowledge Exchange, STICKE, https://sticke.io and https://sticke.deakin.edu.au) imputed the data generated by the workshop participants into the STICKE software to generate the maps. One attendee (LG) acted as the note-taker.

The workshop followed the process and recommendations of the 'LIKE-A-PRO system mapping workshop' manual by Kulis and Szczuka,[64] which was based on principles proposed by Savona et al.[57] The flow of the two-day workshop is detailed in Figure 1. Briefly, all attendees were emailed a pre-workshop information package one month before the workshop, which included brief preparatory readings and assignments to orient attendees to key concepts (see supplemental File 1). Participants were instructed to each "prepare [their] own lists of five or more (i) key social determinants of PA and (ii) key social determinants of SB of the family members," to facilitate a quick entry into the process of systems mapping on the day of the workshop.

As per the recommendations of the 'LIKE-A-PRO system mapping workshop' manual,[64] session one began with a short introduction by the facilitators followed by an ice-breaker that allowed attendees to get to know each other. This was followed by a presentation from AL

introducing systems mapping and the STICKE software. A subsequent presentation from RR briefly overviewed PA benefits, prevalence, and definitions, clarifying that international PA guidelines[63] of 150 min of moderate-to-vigorous intensity aerobic activity per week for adults and 60 minutes per day of moderate-to-vigorous intensity aerobic activity for children and youth should be considered the target behavior when considering social determinants for the PA portion of the workshop. This represented the first boundary object of the mapping activity.[65]

For session two, RR presented similar benefits, prevalence, and definitions, but this time focused on reducing SB. As with the PA content, this concluded with the definition of SB, commensurate with "any waking behavior characterized by an energy expenditure ≤1.5 metabolic equivalents, while in a sitting, reclining or lying posture".[11] While international guidelines are not yet fully agreed upon for reducing SB,[66, 67] Canadian guidelines (adults < 8 hours of sitting; children and youth to limit sitting and <2 hours of recreational screen time) were used as a conceptual benchmark when considering social determinants.[12, 68]

Both sessions were subsequently followed by a brief overview of the social environment, positioning where it is located within the socioecological scope of PA[26] and SB[30] determinants, and then using the taxonomy by Haughton McNeill et al.[44] to represent the breadth and boundary conditions of the accepted determinants within the systems map. This taxonomy was used frequently throughout the workshop, often displayed on the projector screen, to help the group decide whether any proposed determinant fitted the scope of the social environment. The presentation concluded with a discussion of many potential key constructs and subsequent definitions of these constructs in the social environment linked to family systems movement behaviors, based on Rhodes et al.[24] After these presentations, the process of building the map began using stakeholder participation[69] and group model building[70] processes.

Building the maps

Workshop participants and facilitators began by populating a shared digital whiteboard, projected onto a screen, with potential social environment determinants. Before discussing the determinants, participants were asked to prioritize them, from those which may have the strongest impact and that may be the most universal, operating across various contexts. The group drew upon their pre-workshop preparatory tasks and contributed two determinants per person in consecutive order around the room. This first stage was where the participants compiled a list of the dynamic factors that they believed drive PA. By sharing two determinants each, participants could prioritize from the list of variables they had prepared, adjusting based on the existing content on the whiteboard until no further elements were proposed. The group worked to define each determinant as it was added to the whiteboard for clarity. The resulting determinants were transformed into a connection circle on the whiteboard using the STICKE program.

In the next phase, participants worked as a group to identify causal relationships between the variables on the circle, with the facilitators eliciting the direction (positive or negative) of the relationship between two variables and discussing the direction with the workshop participants until reaching a consensus. The group also worked to achieve consensus regarding the robustness of the proposed relationships; relationships that were debated as uncertain or weak in past research literature were not included in the map. After two rounds of the participants and facilitators taking turns to add paths, the modelers used STICKE to transform the connection circle into an initial version of a system map.

Following a break, the session resumed with participants revising the map through review and verification of the consensus that was reached. The facilitators then guided a process to initiate the identification of feedback loops (i.e. where the outputs of causal chains between

factors in the map feedback into the original input), which are one way of considering potentially strong leverage points for action.[71, 72] This concluded day one of the workshop. Identical procedures were replicated for SB on day two.

Refining and validating the maps (post-workshop)

The steps for refining and validating the maps, and the consensus process rules, were agreed by all participants before the workshop concluded. After the workshop, the facilitators returned to the original list of determinants and compared these with key reviews of the social environment and nuclear family systems in PA and SB featured in the suggested pre-reading for the workshop (see Supplemental File 1). The aim of this second appraisal was to simplify/aggregate the list of determinants to the same level of abstraction (e.g., to not have a generalized measure of social support with a highly specific measure of social support) and to suggest any potential missing determinants that are substantiated in the evidence-base of the workshop pre-reading. Following this procedure, all paths among the determinants were also scrutinized, again based on evidence from the prereading and a conceptual understanding of the social environment research in PA and SB. The facilitators worked for consensus between each other and then presented all suggested changes to the workshop attendees via email. As agreed during the workshop, all attendees were asked to evaluate the proposed changes and vote independently on each change (rather than a collective single vote on all changes) using a worksheet that accompanied the proposed changes. This entire procedure was repeated for two subsequent stages: stage 1 included the agreement upon eligible determinants in the PA and SB models; stage 2 included agreement on any proposed changes to the paths within the systems map. All changes that received >65% approval of the workshop participants were included in the

final systems maps. For similar use of this nominal group method to develop consensus and similar thresholds see Hagger et al.[73] and Kwasnicka et al.[74]

Analysis Plan: Network Analysis, Centrality Indicators, and Feedback Loops

The structure of the final maps was analyzed using network analysis with STICKE to identify four indicators of centrality, which represented one method of considering potential points in the system for future intervention: (1) eigenvector, with high values representing the leverage points in the system; (2) degree, with high-degree elements indicating the system elements that are sensitive to change; (3) closeness, with high values representing resilient elements; and (4) betweenness, with high values representing bottlenecks/gateways into the system.[71] As there are no absolute cut-off scores for centrality measures, we followed common practice with other system maps reporting and highlighted the four concepts with the largest centrality scores as critical centrality points.[75]

In the next step, feedback loops in both system maps were identified using KUMU software.[76] After the initial identification of all feedback loops, we proceeded with two approaches, aimed to reduce of the number of loops and identify key loops. The aim of the creation of these submaps was to explore feedback loops that are influencing the most central factors in the broader system. In both approaches, key loops were identified using the highest values centrality indicators as the organizing principle for system map reduction. The first approach involved an attempt to reduce the number of feedback loops by extracting all loops that involved the variables with the highest centrality values (one variable per each centrality index) in the original maps. This approach resulted in a small reduction only, with >50% of loops being retained. In the second approach, the 10 variables with the highest values of centrality measures (i.e., closeness, betweenness, eigenvector, and degree) were retained in the sub-system maps.

The remaining variables, with centrality indicators values lower than the highest 10 values for either of the centrality indicators were removed. These steps resulted in retaining 14 variables in the reduced PA system map and 15 variables in the reduced SB system maps, and a substantial reduction of feedback loops, with < 15% retained.

Results

Through the process described in our methods, facilitators and attendees co-produced illustrative system maps of the social environment determinants of PA and SB in the family system. Below, we provide an overview of the components of each system, and the final map.

Social Environment Determinants of Physical Activity

Facilitators and experts at the meeting elicited 35 potential social environmental determinants of physical activity, with content coverage across the five key domains of Haughton McNeill et al.[44] during the first day. The group then worked together to build the proposed paths among these determinants and the direction of the paths. Overall, the system map had 50 paths connecting any two determinants. The resulting system map and the network analysis from day one can be found in Supplemental Figure 1.

After the workshop, the facilitators returned to the original list of PA determinants. RR, followed by input from AL, collectively suggested 17 changes to the determinants in the PA systems map (see Supplemental File 2). These included amalgamations of determinants for simplification (k = 2), extensions of terms to increase the coverage of relevant content (k = 2), redefinitions of determinants to align with the current social environment or family PA literature (k = 5) and removal of determinants because they already had domain coverage with determinants in the model or they are outside the scope of the social environment (k = 8). All suggested changes were passed. The final list of determinants, their definitions, and their location

in Haughton McNeill et al.'s[44] taxonomy is reported in Table 1. The final determinants list included 23 variables, with strong representation in the domains of social support / social networks (k = 16) and social cohesion / social capital (k = 16), followed by some representation of socioeconomic position and income inequalities (k = 5), neighborhood (k = 5), and discrimination (k = 2).

The second step in the refining process involved a similar voting procedure on the paths within the map. RR, followed by input from AL, included the original 50 paths in addition to 49 changes (see Supplemental File 3). The proposed changes included seven deletions of the original paths from the workshop day and 42 new paths. Overall, 91 of the 99 total suggestions were passed. Seven of the paths that did not receive support were new proposed paths and one suggestion to delete a path was not supported. Interestingly, the lack of consensus was centered on two specific variables (socioeconomic position, flexibility in roles and duties) and their proposed consequences within the map.

The final system map for social environment determinants of PA in the family system is presented in Figure 2 (corresponding centrality measures are included in Supplemental file 4). The map had 85 connections. For eigenvector leverage points (i.e., determinants that, when altered, have positive ripple effects throughout the system), family PA values and priorities scored highest (.43), followed by shared mode/co-activity (.31), family cohesion/organization (.29), and support external to the nuclear family (.28). Family PA values and priorities (21), followed by shared mode/co-activity (12), family logistical support (11), and family cohesion/organization (11) were the four highest indicators of degree (i.e., number of connections between determinants). Family PA values and priorities (.72) also had the highest value for closeness (i.e., the shortest path from one determinant towards all separate other

determinants in the system), followed by support external to the nuclear family (.62), family logistical support (.61), and informational supports within the family and community (.57). Finally, family PA values and priorities (74.6) also had the highest value for betweenness (i.e., gateway or a bottleneck within the system), followed by inclusiveness of community infrastructure and programs (28.5), family logistical support (22.1), and informational support within the family and community (19.7).

The final system PA map, with all identified variables and connections, included 1,029 feedback loops (Figure 2). The submap, including 14 variables with the highest values of centrality indices, included 24 feedback loops (see Supplemental Figure 2), with 5 loops having only 2 variables/ 2 connections. The remaining 19 feedback loops (see Supplemental File 5) had between 3 and 6 connections.

Across 19 loops with 3-6 connections, all were reinforcing (in this instance, all connections between variables in the identified loops were positive). Across the feedback loops, 11 shared three variables linked in a specific order: Stronger family PA values and priorities were related to higher family connectedness and engagement in the community, which in turn was related to higher level of support external to the nuclear family. Higher support external to the nuclear family was, in turn, either related to stronger family connectedness and engagement in the community, or to 3 other variables (family logistical support, or social norms extended to the nuclear family, social reward from family/community members), linked either directly back to higher family PA values and priorities, or indirectly via subsequent variables in the loops (see Supplemental File 5; Supplemental Figure 2).

Social Environment Determinants of Sedentary Behavior

Facilitators and experts at the meeting elicited 30 potential social environmental determinants of SB in the nuclear family system during the second day. Identical to the day one procedures for PA, the group then worked together to build the proposed paths among these determinants and the direction of the paths. Overall, the system map had 31 paths connecting any two determinants. The resulting systems map from day two and results of the network analysis can be found in Supplemental Figure 3.

After the workshop, the facilitators also returned to the original list of SB determinants. Like the procedures for PA, RR, followed by input from AL, suggested 18 changes to the determinants in the SB systems map (see Supplemental File 6). These included amalgamations of determinants for simplification (k = 2), extensions of terms to increase the coverage of relevant content (k = 1), redefinitions of determinants to align with current social environment or family SB literature and the PA system map created on day one of the expert meeting (k = 7), removal of determinants because they already had domain coverage with determinants in the model or they are outside the scope of the social environment (k = 6), and the addition of determinants that have been identified as important in the PA systems map and are also relevant to SB (k = 2). All changes but one (a redefinition recommendation) were passed. The final list of determinants, their definitions, and their location in Haughton McNeill et al.'s [44] taxonomy is reported in Table 2. The final determinants list included 21 variables, with particular representation in the domains of social support/social networks (k = 16) and social cohesion/social capital (k =11), followed by representation of socioeconomic position and income inequalities (k = 5), neighborhood (k = 4), and discrimination (k =1).

Like the PA map, the second step in the refining and validation process involved a similar voting procedure on the paths within the map. RR, followed by input from AL, included 23 out

of 31 original paths in addition to 71 changes (see Supplemental File 7). The proposed changes included seven deletions of the original paths from the workshop day and 64 new paths. Overall, 58 of the 71 total suggestions were passed. Twelve of the paths that did not receive support were new proposed paths and one original path was not supported. Interestingly, the lack of consensus was generally centered on dog ownership (six unsupported paths) and the home environment (four unsupported paths) as either proposed antecedents or consequences within the map.

The final system map for the social environment determinants of SB in the nuclear family system has 75 total connections and is presented in Figure 3 (corresponding centrality measures are included in Supplemental file 8). The key eigenvector leverage points included family cohesion and organization (.36) and informational supports within the family and community (.36), followed by family interest in sedentary behaviors (.30), family logistical support (.30), and verbal encouragement from family and community members (.30). Family cohesion and organization (17), followed by family interest in sedentary behaviors (13), informational support within the family and community (12), and verbal encouragement from family and community members (10) were the four highest indicators of degree. Informational supports within the family and community (.67) had the highest value for closeness, followed by family cohesion and organization (.65), family logistical support (.63), family interest in sedentary behaviors (.61), and flexibility in roles, duties and responsibilities of family members (.61). Finally, family cohesion and organization (37.4) had the highest value for betweenness, followed by family socioeconomic status (27.3), family logistical support (19.1), and informational support within the family and community (18.5).

The final SB system map, with all identified variables and connections, included 469 feedback loops (Figure 3). The submap, including 15 variables with the highest values of

centrality indices, included 67 feedback loops (see Supplemental Figure 4), with 7 loops having only 2 variables and 2 connections. The remaining 60 loops (see Supplemental File 9) had 3 to 7 connections.

Among those 60 identified feedback loops, 22 were balancing (in this case, including one negative connection) and 38 loops were reinforcing (all connections between variables were positive, or two connections were negative and the remaining were positive in a loop including at least 4 connections). All balancing loops included one of two types of specific chains of associations (see Supplemental File 9; Supplemental Figure 4), In the first type, family interest in SB activities and/or SB time in the family influenced family cohesion/organization. For example, higher family cohesion meant seeking more informational support for SB reduction in community or family, which in turn led to lower shared SB in the family, which was related to lower family cohesion and organization. The other type of balancing loops included a chain of family cohesion/organization which influenced family interest in SB activities and/or shared SB. For example, higher family cohesion and organization led to more shared SB in the family, which in turn was associated with more family interest in SB activities. More SB activities led to lower regulatory support for SB reduction in family which, subsequently, was related to lower family cohesion and organization.

Across 38 reinforcing loops, 24 included family interest in SB activities, and 13 included shared SB in the family (see Supplemental Table 9). For example, higher informational support for SB reduction in family/community led to less shared SB in the family, which in turn led to less family interest in SB activities, then more family logistical support for SB reduction, followed by higher verbal encouragement form family/community members. In turn this led to back to increased informational support in the family/community.

Discussion

The purpose of this research was to develop two system maps (PA, SB) of the social environment focused on the core/nuclear family system. The development of these maps adhered to a clear theoretical framework of five pillars of the social environment[44] and the maps were created through a thorough process: a two-day 16-researcher, in-person participatory workshop, followed by several rounds of continuing online participation of the researchers to refine the maps. The resulting system maps illustrate the likely social environment determinants in the family system for PA and SB, the possible paths of cause and effect between the determinants, potential differences and similarities between the two behaviors, and leverage points for intervention.

A key strength of a system mapping procedure is the participatory approach of engaging a team in the designation of the important determinants within that system.[55, 61] In this case, the research team drew upon their research readings and experience to contribute to the list of the most impactful and relevant social environment determinants of PA and SB through an iterative procedure. The composition of variables on these lists, when categorized by the five pillars of the social environment taxonomy,[44] showed that >70% of the variables in both maps involved social support or social network factors, while <24% of the variables included socioeconomic and income inequalities, or neighborhood factors. These noteworthy differences in representation are supported by theory and make particular sense for a social environment systems map. Specifically, the built environment and socioeconomic factors are only inclusive of the social environment when they intersect with the cultural milieu within which people function and interact.[43] By contrast, social support and social network factors (as well as social cohesion and social capital) are central examples of interpersonal factors in a socioecological model.[39] A broad

systems map of movement behavior determinants would include a more balanced representation of social, environmental, socioeconomic, and individual factors determining physical activity.[58] The rich number of determinants present in the social categories in these maps thus validates our focus on the social environment, which has been traditionally underrepresented in understanding the determinants of health behaviors.[37, 77]

When comparing the variable list for both the PA and SB maps, there is clearly a lot of overlap between the proposed social environment antecedents. This is not surprising, because SB and PA are inversely correlated in the large-to-medium effect sized[78] range,[27-29, 79-81] so it stands to reason that many of their antecedents will also be shared. The only noteworthy difference among representation of determinants in these behaviors was in the social cohesion and social capital categorization, with 70% representation of determinants in PA but only 52% representation in SB. We propose that the difference in this social environment category between the two behaviors is likely due to the cost and performance differences between SB behavior and PA. Specifically, SB is almost ubiquitous with many different forms of behaviors in the family home (e.g., screen time, board games, reading, sitting and socializing, eating) and many leisure-time SBs are designed to be independent and low cost.[82, 83] By contrast, many PAs include some economic cost (e.g., recreation centers, programs, equipment, attire) and are often associated with social opportunities or outcomes.[26, 84, 85]

It is also important to note that determinants representing potential social discrimination were present in both systems maps, but these had the smallest overall representation. Similar to the built environment and socioeconomic factors, discrimination-related determinants will also be present in other layers of the socioecological model (e.g., policy, built environment, programs) or in social contexts other than the family system (e.g., workplace, community) and so

it is not surprising that discrimination-related determinants are included in the system map but have limited representation.[39, 44] Further, promotion of underserved and vulnerable populations is an important area of burgeoning research in movement behaviors generally,[86-88] and thus discrimination-related determinants may be further refined and developed as this research matures.

While the identification of key determinants in the social environment for the nuclear family system is clearly important, the advantage of system maps over past frameworks in this research space[24, 51-54] is through the analysis of the proposed structural properties in the map. Through the in-person workshop and online follow-up, the team identified 85 connective paths among its 23 determinants for the PA systems map and 75 paths among 21 determinants for the SB map. The structure of the final maps were analyzed using a combination of network and feedback analysis methods to identify key targets for intervention. A similar determinant, representing shared family motivation toward the target behavior (family values and priorities in physical activity, family interest in sedentary behavior activities), showed the highest overall indicators of centrality across both maps and was present in most of the feedback loops in our submap analyses. This suggests that shared family motivation, when intervened upon, is likely to have positive ripple effects throughout the system to evoke changes[89] and will affect other determinants quickly around the system because the construct is a gateway with a number of close ties to other determinants.[71] For example, our PA submap of key feedback loops showed a balancing loop whereby stronger family PA values and priorities were related to higher family logistical support, which in turn was related to higher shared mode / co-activity in the family and linked directly back to higher family PA values and priorities.

From a theoretical perspective shared motivation[38] are inclusive of the concepts of collective identity,[90] shared goals,[91] homophily,[92] and "we" intentions.[93] In the context of the family system this would also include shared attitudes, enjoyment and beliefs between couples or among the family toward a PA or SB.[94] The concept of shared motivation is also likely an antecedent, or adjacent to a family social identity (i.e. collective categorization in a particular role) about these behaviors.[95, 96] Interestingly, there is limited research that has explored shared motivation within the family system at present, despite the connectivity of this proposed determinant within these systems maps. It has been well established that SB and PA are correlated in the family system,[17, 97, 98] yet motivation-based interventions at the collective level are sparse. A series of studies on collaborative ("we") planning in PA[99-105] may provide some insight into the effectiveness of developing shared goals, despite some marked differences between the concepts of motivation and planning.[106-108] Overall, the results of these tests have been mixed in terms of changes to behavior generally, and in comparison to individual-level motivation approaches. Similarly, interventions focused on promoting PA social identity,[109-111] primarily through group cohesion techniques,[112] have shown some effectiveness, yet this body of research has not focused on the nuclear family. Overall, these systems maps highlight the potential centrality and subsequent feedback loops that illustrate the importance of intervening on shared family motivation and the need for innovative and sustained research on this determinant in reducing SB and increasing PA.

Family logistical support (i.e., organizing a child's PA or alternate activities from SB; providing transportation to activities) had the second highest overall ratings of centrality across both systems maps and also featured prominently in our feedback loop submaps. Tangible aid has been a foundational social support concept in health behaviors for nearly half a century[113]

and logistical support, with a focus on the parent-child portion of the family system has had considerable research in PA and some similar development in reducing SB.[24] Specifically, parental support of child PA, of which logistical support is a key component,[114] is arguably the largest correlate of child PA,[97, 115] and the results appear similar for SB.[116-118] Interventions in the family system that target improvements in parental logistical support of PA have shown positive findings,[119, 120] although current evidence only supports short-term changes, thus illuminating the need for more refined and sustained interventions on family logistical support. Thus far, there is also evidence to suggest that parent-adolescent logistical support may be less effective than younger children support for promoting PA and reducing SB,[121, 122] presumably due to the rise in independence in the teenage years.[123]

Family cohesion and organization were also central in both systems maps and featured in a majority of key feedback loops in our submaps. These are key properties of family functioning[124, 125] and central to family-systems models of child development[126-129] with links to child health and well-being.[130, 131]. It is interesting to note that family cohesion and organization were particularly key to reduced SB (i.e., all four indicators of centrality were among the highest in the map). For example, in the SB systems map, a balanced loop showed higher family cohesion and organization linked to more shared SB in the family, which in turn was associated with more family interest in SB activities, leading to lower regulatory support for SB reduction in family which, subsequently, was related to lower family cohesion and organization. This is also supported by research literature that shows families with higher family functioning (i.e., social-structural properties of the family environment including conflict, cohesion, organization, quality of communication) engage in more movement-based activities together,[10, 132] but also that lower family functioning is generally related to higher levels of SB.[133, 134] Unfortunately, this is

likely because screen-based activities are sometimes used as a stand-in for less functional parenting practices[117, 135] or they can be a reprieve or time replacement for a family that has low cohesion.[132, 134]

Interventions to improve family cohesion and organization often involve case management,[136, 137] problem solving,[138] and positive psychology,[139, 140] and child-parent family functioning specifically may also be improved through targeting increased parenting efficacy.[141, 142] More recent evidence, however, also suggests that family PA promotion may increase family function, particularly cohesion and organization among families with elementary school aged children,[10] indicating the centrality of family functioning as cause and effect in the social environment related to movement behaviors. Aligned with this finding, family cohesion and organization are likely tied to participating in PAs together, which had key centrality parameters and was included several feedback loops in the PA map. Thus, promoting family initiatives to reduce SB and increase PA, particularly among families with children aged 6 to 12 years, may foster shifts in family roles and schedules to perform more activities together, and improve family function as a result of these experiences.[10]

Some other key determinants from both the family system and the broader social environment emerged as key markers of centrality and feedback loops in the maps. Informational support from family and community ranked as a top centrality parameter across both maps. From a theoretical perspective, informational support is often considered foundational to eventual shifts in attitudes and intentions, leading to changes in behavior.[143, 144] Thus, community information (e.g., in schools, recreation centers, social media, etc.) that supports why and how families can move more should help to promote discussion and encouragement towards these behavior changes within the family system. The role of informational support from family and

community was particularly prominent in the SB map compared to the PA map. For example, a reinforcing feedback loop in the SB system map showed higher informational support for SB reduction led to less shared SB in the family, which in turn linked to less family interest in SB activities, to more family logistical support for SB reduction, followed by higher verbal encouragement form family/community members, and back to increased informational support. This higher prominence in the SB map is likely because most parents are already aware of the numerous health and development benefits of PA for their children.[145] By contrast, very few people are aware of reduced SB guidelines.[146] Therefore, our map is likely compensating for the foundational importance of this information to behavior change.

Finally, both system maps also highlighted key social environment constructs outside the family system. Specifically, our SB map outlined the potential role of socioeconomic status on SB and our PA map highlighted the importance of inclusiveness of community infrastructure and programs and supports external to the nuclear family more generally. These emphasize the importance of community social infrastructure on behavior, as well-established in socioecological models.[32] From an intervention perspective, the particular centrality that our PA map had on programs and supports external to the family likely derives from how PA is often performed outside of the home and thus it is reliant on larger, community infrastructure contributions.[147] Sustained resources to enable inclusive programing and social infrastructure to foster movement behaviors are recommended.

Despite the strengths of a systems mapping approach, our study also has limitations that warrant mention. First, the outcomes from participatory systems mapping procedures are dependent on the group composition and our group was primarily comprised of researchers with health psychology training from western high-income nations. Thus, while we did have

researchers within other domains of expertise participate (e.g., public health, family systems, kinesiology, co-production), our maps may have differed with researchers in other allied disciplines or cultures, or with the inclusion of various non-academic stakeholders. Despite the lack of representation of non-academic stakeholders, most researchers in the workshop had previously worked on participatory research with non-academic stakeholders in the field of PA and SB and included these experiences and insights in the exercise. Second, while these system maps are based on research evidence, the maps themselves have not been tested with population sampling data. Thus, these systems maps are primarily of use to galvanize future research and intervention efforts and future empirical testing of the maps is needed. In addition, nearly all of the determinants and paths in these maps were overwhelmingly supported by the team of participants, yet there were some points of divergence in opinion that challenged the trustworthiness of a few aspects of the findings. For example, there was considerable heterogeneity in several paths involving the dog ownership variable in the SB map and this was likely a result of different experiences with dog ownership from the panel (i.e., whether dog owners over-emphasized the importance of this determinant or non-dog owners under-emphasized its importance). Likewise, the group also had to think about the SB map in terms of whether a determinant related to reducing or increasing SB, in terms of its framing, and how this should be articulated best on the map (e.g., interest in SB or interest in reducing SB). Finally, members participating in this mapping process also acknowledged the challenges in selecting key variables among children, youth, and adults that fit within the social environment, and not at the narrower individual level or broader built environment or policy levels of abstraction. The taxonomy of social environment[44] was invaluable to assist in this regard, yet the constrained "middle level" of these maps compared to representation of an entire socioecological map of

each behavior proved challenging. It may be of value to refer to our maps in the context of broader whole-of-system maps that have been built for PA and SB. Furthermore, our selection of network analysis represents only one way to consider potential points for intervention in a system map. While recent concerns have been raised about this approach in isolation,[148] when combined with additional strategies such as examination of feedback loops, exploring where system resources are being taken up or distributed from, and further participatory engagement (which we advocate in this instance) to test the real world appropriateness of intervention ideas,[61] network analysis is a useful tool to inform these conversations. Our approach is an important first step in reshaping the formulation of understanding of the dynamics of determinants of PA and SB in the family environment. Lastly, it must be noted that the selection of feedback loops included in our analysis was not based on rigid criteria. Given the initial identification of 1,042 feedback loops for the PA map and 468 loops for the SB map, it was neither feasible nor practical to describe all of them. Therefore, we included feedback loops based on a filtering process involving the top 10 variables with the highest values of centrality indicators (closeness, betweenness, eigenvector, and degree). A different filtering process may result in other findings.

Conclusions

In summary, the social environment is important to consider for effective promotion of movement behaviors like increased PA and reduced SB, and the nuclear family system is clearly one of the major apertures of focus for this promotion. Using the participatory systems mapping approach we followed a structured, step-by-step format to create PA and SB maps. Our findings highlighted key determinants that are central within the system and thus likely critical targets to consider for potential intervention to produce behavioral changes. These included determinants

within the family system (e.g., shared family interests, values and priorities, family logistical support, family cohesion/organization), as well as key determinants of the broader social environment (e.g., informational support in family and community, socioeconomic position, availability of inclusive physical activity programming and infrastructure). The maps support current evidence on the role of movement behaviors in family systems and socioecological theories, and have utility to galvanize future research and policy to promote PA and reduce SB.

Figure Captions

Figure 1: Flow of the Development of the Systems Maps

Figure 2: Physical Activity System Map of the Social Environment within the Nuclear Family System

Figure 3: Sedentary Behavior System Map of the Social Environment within the Nuclear Family System

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Table 1

Constructs included in the Family Social Environment System Map for Moderate-to-Vigorous Intensity Physical Activity

Construct Label	Definition/Explanation	Position in Haughton McNeill et. Al. (2006) Taxonomy
Inclusiveness of community infrastructure and programs	Diverse PA programming and infrastructure, resulting in high opportunity of MVPA participation for all	Discrimination/ Neighborhood
Inclusive gender and cultural norms in community	Low community bias in terms of PA participation beliefs and values based on the customs, and achievements of people, or other social groups	Discrimination
Social norms external to the nuclear family	Positive PA participation beliefs and values from referents external to the core family system	Social cohesion/ Social networks
Support external to the nuclear family	Supportive PA participation practices from referents external to the core family system	Social support/ Social cohesion
Affordability/ payment flexibility of community infrastructure and programs	PA programming and infrastructure that includes low cost and flexible payment options, resulting in high opportunity of MVPA participation for those of lower socioeconomic positions	Socioeconomic position and income inequalities/ Social capital/ Neighborhood
Family PA values and priorities	Family priority and identification of PA in comparison of other interests and values	Social support and social networks/ Social cohesion
Family SES	Family household income, average formal education, and occupational status	Socioeconomic position and income inequalities/ Social capital
Family connectedness and engagement in the community	Solidarity in interests, values, shared resources and activities among the community	Social cohesion
Family PA modeling	Regular demonstration of PA by referents within the family system	Social support
Home physical environment	Affordances and physical space available in the home (including backyard) for PA	Neighborhood
Informational support in family/community	Access to informational and discussions about PA benefits and challenges	Social support
Shared mode/ co-activity in family	Family aggregation of regular physical activity	Social support and social networks/ Social cohesion
Flexibility in roles, duties and responsibilities of family members	Flexibility among family members in duties and responsibilities such as flexible working hours, external obligations from the core family system, and care responsibilities	Social capital/ Social support and social networks
Family logistical support	Planning or organizing a child's PA; providing transporting to sports or other PAs.	Social support/ Social capital

Size of family network	Number of family members, extended family members, friends, and supportive community	Social network/ Social capital
Negative social control by family /community members	Pressure, threats or coercion that systematically restricts someone from making independent PA choices	Social support/ Socioeconomic position
Family cohesion and organization (low entropy)	Organization across the family home environment; for example, family cohesion occurs in homes that are organized and structured	Social support/ Neighborhood/Social cohesion
Interpersonal safety in family and community	Perceptions of trust and security within the community and family	Social support/ Socioeconomic position/ Social cohesion
Verbal encouragement from family/ community members	Encouragement of PA participation	Social support
Social reward from family/community members	motivational and pleasurable aspects of interactions with other people after PA participation	Social support/ Social cohesion
Regulatory support in family	Family rules and standards of practice in PA	Social support/ Socioeconomic position/ Social cohesion
Physical environment safety in community	Safety from personal and property crime in the neighborhood	Neighborhood/ Social cohesion/ Social network
Descriptive PA Norm in community	Visibility of PA within the community	Social cohesion/ Social networks

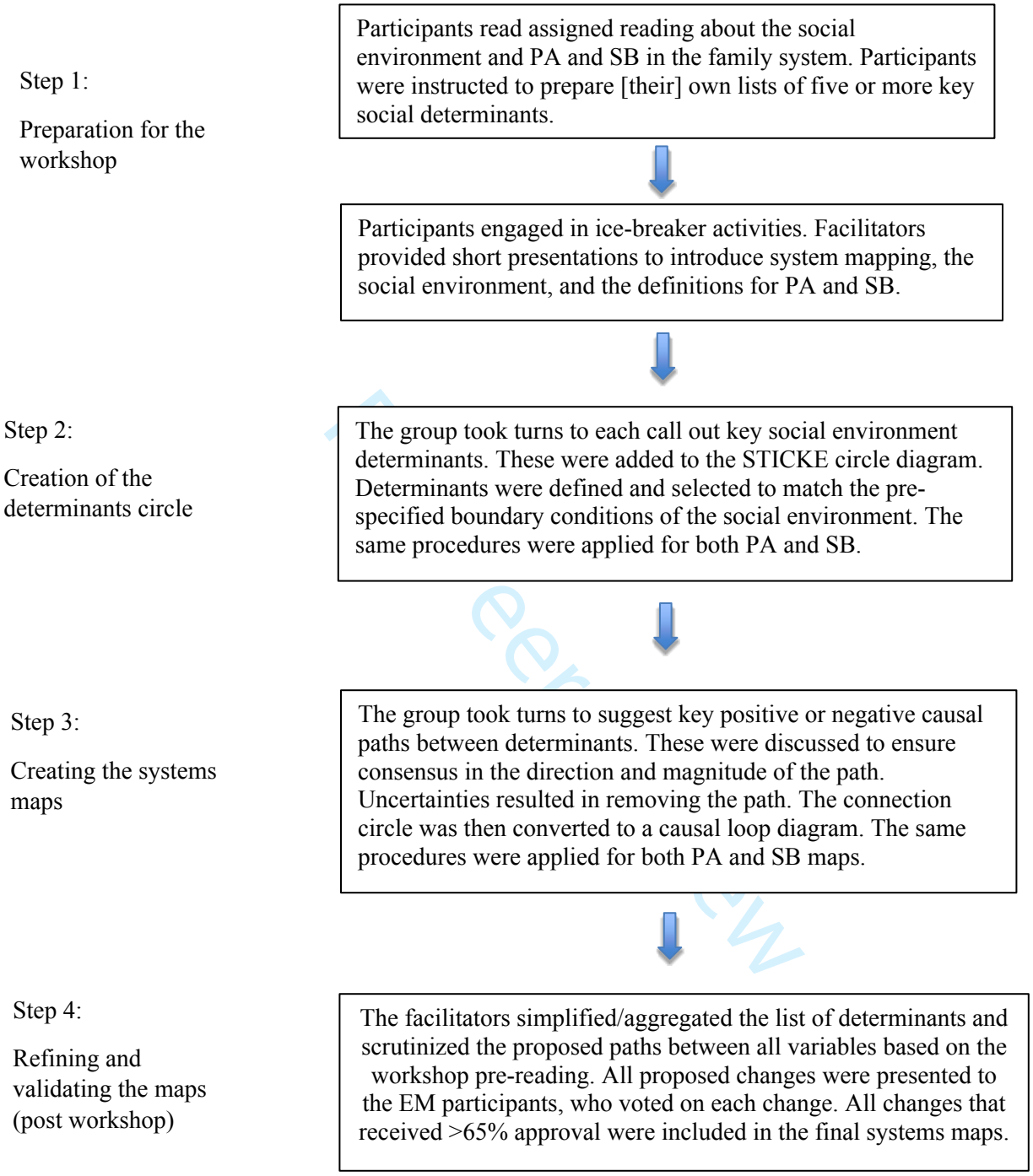
Table 2

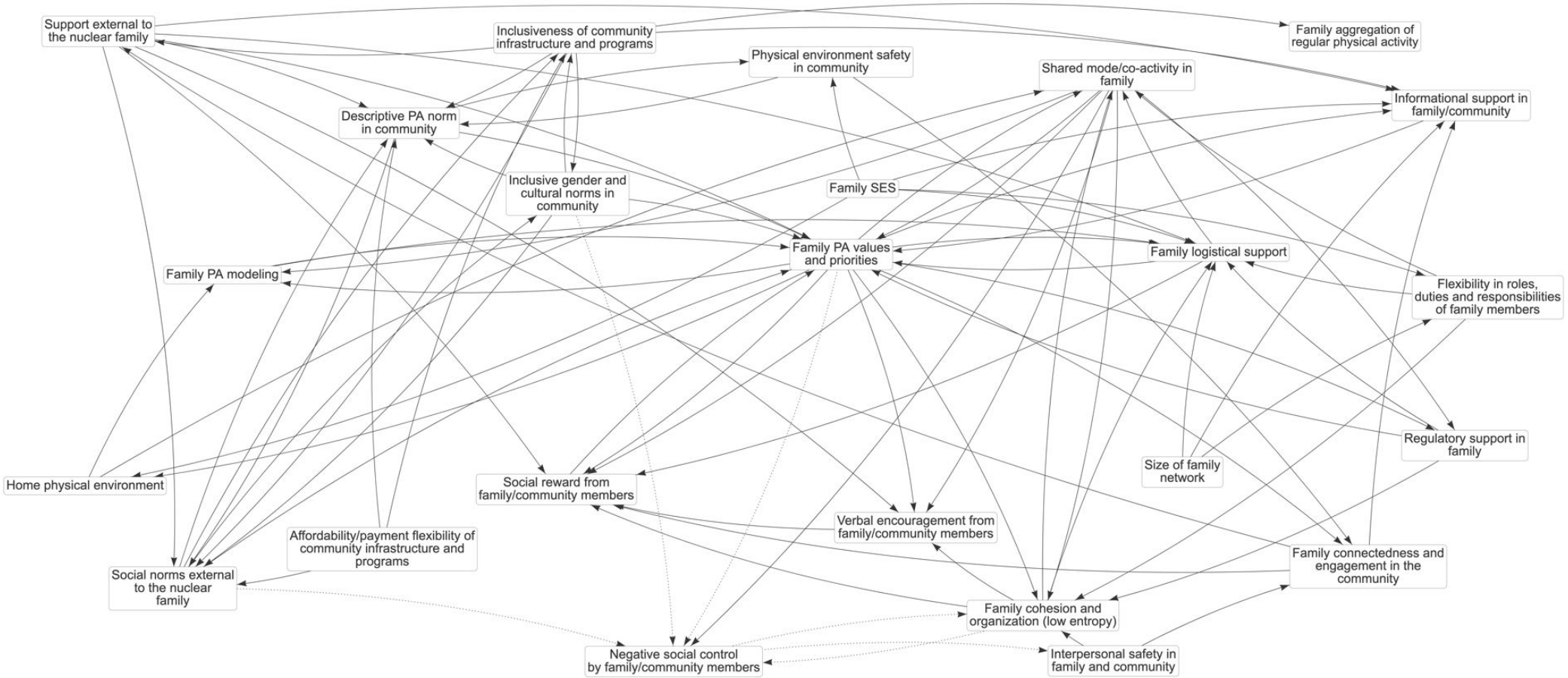
Constructs included in the Family Social Environment System Map for Sedentary Behavior

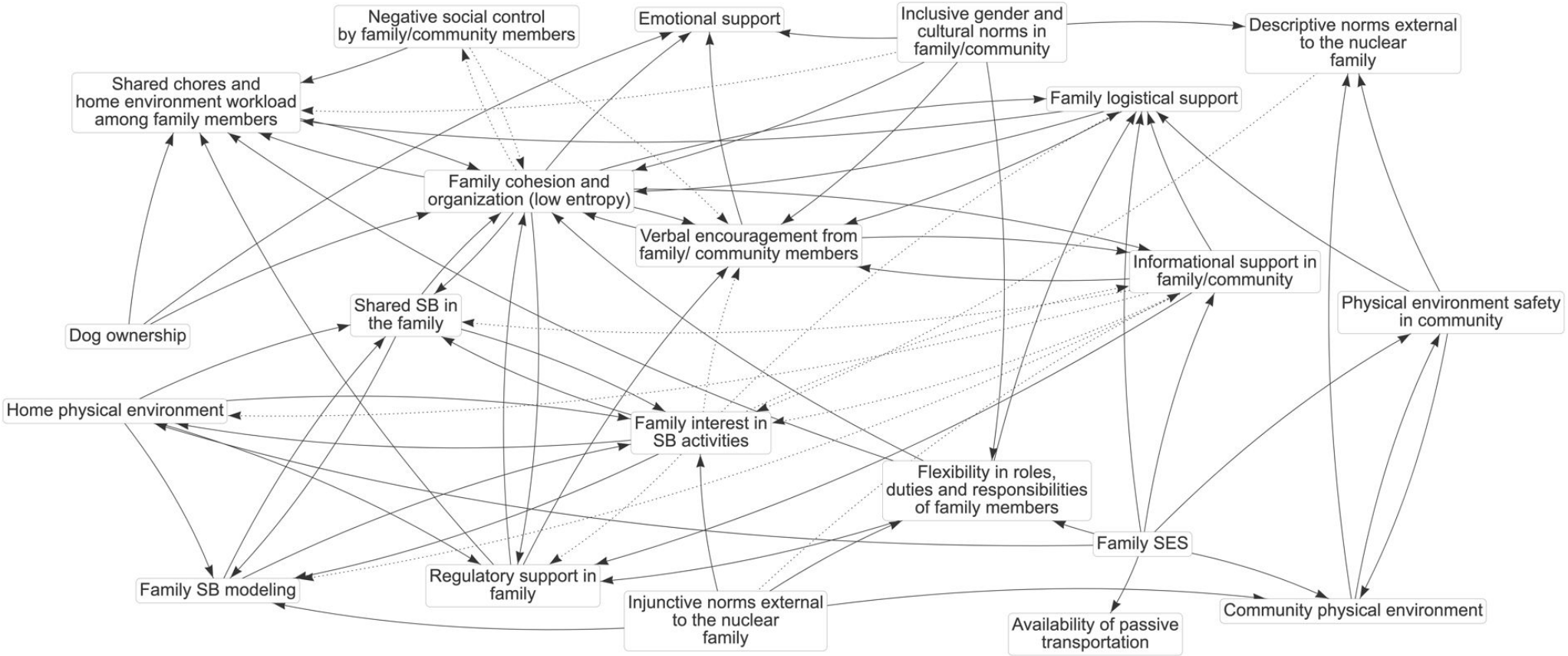
Construct Label	Definition/Explanation	Position in Haughton McNeill et. Al. (2006) Taxonomy
Flexibility in roles, duties and responsibilities of family members	Flexibility among family members in duties and responsibilities such as flexible working hours, the ability to "unplug from the internet," external obligations from the core family system, and care responsibilities	Social capital/ Social support, Socioeconomic position, and social networks
Availability of passive transportation	Accessibility of family and community transportation modes that facilitate sitting	Neighborhood factors
Family SES	Family household income, average formal education, and occupational status	Socioeconomic position and income inequalities/ Social capital
Family logistical support	Planning or organizing activities to replace a child's SB; providing transporting to other activities.	Social support/ Social capital
Emotional Support	Showing care and compassion for another person (verbal or nonverbal).	Social support
Regulatory support in family	Family rules and standards of practice in SB	Social support/ Socioeconomic position/social cohesion
Home physical environment	Affordances and physical space available in the home (including # of screens, affordances of video games, board games, etc.) for SB	Neighborhood
Community physical environment	Affordances and physical space available in the community (including chairs v. standing areas, trails and walkways v. cafes, etc.) that facilitate SB	Neighborhood
Dog ownership	Presence of a dog in the family home.	Social support and social networks
Physical environment safety in community	Safety from personal and property crime in the neighborhood	Neighborhood/ Social cohesion/ Social network
Family interest in SB activities	Family priority and interest in SB in comparison to other interests and values.	Social support and social networks/ Social cohesion
Family SB modeling	Regular demonstration of SB by referents within the family system	Social support
Informational support in family/ community	Access to informational and discussions about limiting SB benefits and challenges	Social support
Negative social control by family /community members	Pressure, threats or coercion that systematically restricts someone from making independent SB limiting choices	Social support/ Socioeconomic position
Shared chores and home environment workload among family members	The distribution of family duties in the family home, inclusive of chores, duties and responsibilities (e.g., walking the dog,	Social support/ Social cohesion and social capital

	cleaning, garbage disposal, meal preparation, etc.)	
Inclusive gender and cultural norms in family/community	Low family/ community bias in terms of limiting SB for other activities beliefs and values based on the customs, and achievements of people, or other social groups	Discrimination
Injunctive norms external to the nuclear family	Supportive SB limiting beliefs and values from referents external to the core family system	Social cohesion/ Social networks
Descriptive norms external to the nuclear family	Visible SB limiting practices from referents external to the core family system	Social support/ Social cohesion
Verbal encouragement from family/ community members	Encouragement of limiting SB	Social support
Shared SB in the family	Family aggregation of SB	Social support and social networks/ Social cohesion
Family cohesion and organization (low entropy)	Level of organization across the family home environment; for example, low family entropy occurs in homes that are organized and structured.	Social support/ Neighborhood/ Social cohesion

Figure 1: Flow of the Development of the Systems Maps




Support external to the nuclear family
Inclusiveness of community infrastructure and programs
Family aggregation of regular physical activity
Physical environment safety in community
Shared mode/co-activity in family
Informational support in family/community
Descriptive PA norm in community
Inclusive gender and cultural norms in community
Family SES
Family PA values and priorities
Family logistical support
Family PA modeling
Flexibility in roles, duties and responsibilities of family members
Regulatory support in family
Size of family network
Home physical environment
Social reward from family/community members
Verbal encouragement from family/community members
Affordability/payment flexibility of community infrastructure and programs
Family connectedness and engagement in the community
Social norms external to the nuclear family
Family cohesion and organization (low entropy)
Negative social control by family/community members
Interpersonal safety in family and community


Negative social control by family/community members
Emotional support
Inclusive gender and cultural norms in family/community
Descriptive norms external to the nuclear family
Shared chores and home environment workload among family members
Family logistical support
Family cohesion and organization (low entropy)
Verbal encouragement from family/ community members
Informational support in family/community
Physical environment safety in community
Shared SB in the family
Dog ownership
Home physical environment
Family interest in SB activities
Flexibility in roles, duties and responsibilities of family members
Family SES
Family SB modeling
Regulatory support in family
Injunctive norms external to the nuclear family
Availability of passive transportation
Community physical environment

Synergy Expert Meeting
Participant Information Pack

European Health Psychology Society
Synergy Expert Meeting 2023

3rd to 4th of September 2023

University of Bremen, Bibliothekstraße 1, 28359, Bremen.

All we know about Physical Activity & the social environment: A systems mapping approach

Facilitators:

Professor Ryan E. Rhodes
The University of British Columbia, and University of Victoria

Professor Aleksandra (Aleks) Luszczynska
University of Social Sciences & Humanities, and University of Colorado at Colorado Springs

Welcome

Dear Participant,

Welcome to the Synergy Expert Meeting (EM) 2023 in Bremen, Germany. This booklet includes further information about the EM location, the program, and list of social events. We have also included some practical information and our contact details. For additional practical information including transport, further suggestions for places to visit, and places to eat and drink, please visit the conference website: https://2023.ehps.net/travel-info/

Expert Meeting Description

In this Expert Meeting, we aim to go beyond the dominant models for explaining and influencing initiation and maintenance of physical activity. We will achieve this by (1) integrating the broad list of social environment factors related to physical activity with a central focus on nuclear family members (a dyad of romantic partners, parents or legal guardians, and children) and (2) combining the factors into a system map of physical activity. In particular, the objective of the Expert Meeting is to collaboratively develop a publishable system map giving insight into complex family environment factors influencing physical activity, shifting the focus towards a system-based logic approach (instead of process-oriented approaches).

Location

The Synergy EM will be held in the University of Bremen. Specifically, in the Institute for Public Health and Nursing Science, Grazer Str 2, 28359 Bremen, Germany.

Preparation for the EM

Please bring your laptops or tablets if you have them for writing up your comments and group discussions at the meeting. It is likely that all attendees will be needing to charge their laptops though out each day and this will lead to lots of power cables covering the room. Many modern laptops can be charge via USB-C cables rather than the bulky traditional power adaptor. We advise finding out if this is true for your laptop and bringing only a travel adaptor or a small wall plug with a 2-3m USB-C cable. Power supply information (voltage and plug type) can be found at the end of this pack under practical information. There will be Wi-Fi in the room – you will receive instructions for accessing the Wi-fi at the start of the meeting.

All attendees

In preparation for the meeting, the facilitators would like to share with delegates the following information:

1. **Please prepare your own lists of (i) the key social determinants of physical activity and (ii) key social determinants of sedentary behaviors of the family members**

   Both lists should include all key determinants (a minimum of 5 per list). When preparing the list please make sure that the determinants are:
   - Clear and specific (e.g., instead of using 'social support' say e.g. 'parental transportation support for child PA')
   - Should not include adjectives that imply increasing/decreasing (e.g., instead of 'Higher income' one can say 'family disposable income')
   - When possible, default to the positive/neutral version of the determinant (e.g., choose 'cultural gender norms regarding girls/women sport participation' rather than 'negative/positive norms regarding women's/girls' sport engagement')

2. **We recommend the following reading before the workshop:**

See https://drive.google.com/drive/folders/1Hpd7zTq6wyz0MudQFCysTHa9xgOeYwhF?usp=sharing

System mapping approach:

- Savona, N., Macauley, T., Aguiar, A., Banik, A., Boberska, M., Brody, J., Brown, A., Hayward, J., Holbaek, H., Rito, A. I., Mendes, S., Vaaheim, F., van Houten, M., Veltkamp, G., Allender, S., Rutter, H., & Knai. C. (2021). Identifying the views of adolescents in five European countries on the drivers of obesity using group model building, *European Journal of Public Health*, 31 (2), Pages 391–396. https://doi.org/10.1093/eurpub/ckaa251 (available online - open access)
- Rutter, H., Cavill, N., Bauman, A & Bull, F. (2019) System approaches to global and national physical activity plans. *Bulletin of World Health Organization, 97*, 162-165. http://dx.doi.org/10.2471/BLT.18.220533 (available online - open access)

Social determinants of physical activity and sedentary behaviour

- Haughton McNeill, L., Kreuter, M. W., & Subramanium, S. V. (2006). Social environment and physical activity: A review of concepts and evidence. *Social Science and Medicine, 63*, 1011-1022.
- Rhodes, R. E., Guerrero, M. D., Vanderloo, L. M., Barbeau, K., Birken, C. S., Chaput, J. P., & Tremblay, M. S. (2020). Development of a consensus statement on the role of the family in the physical activity, sedentary, and sleep behaviours of children and youth. *International Journal of Behavioral Nutrition and Physical Activity, 17*, 1-31.

3. Other reading

See: https://drive.google.com/drive/folders/1Hpd7zTq6wyz0MudQFCysTHa9xgOeYwhF?usp=sharing

Allender S, Owen B, Kuhlberg J, Lowe J, Nagorcka-Smith P, Whelan J, et al. (2015) A Community Based Systems Diagram of Obesity Causes. PLoS ONE 10(7): e0129683. https://doi.org/10.1371/journal.pone.0129683

Cane, J., O'Connor, D., & Michie, S. (2012). Validation of the theoretical domains framework for use in behaviour change and implementation research. *Implementation Science*, *7*, 37.

Hassmiller Lich, K., Brown Urban, J., Frerichs, L., & Dave, G. (2017). Extending systems thinking in planning and evaluation using group concept mapping and system dynamics to tackle complex problems. *Evaluation and Program Planning*, *60*, 254-264, https://doi.org/10.1016/j.evalprogplan.2016.10.008.

Huelsnitz, C. O., Jones, R. E., Simpson, J. A., Joyal-Desmarais, K., Standen, E. C., Auster-Gussman, L. A., & Rothman, A. J. (2022). The Dyadic Health Influence Model. *Personality and Social Psychology Review*, *26*(1), 3–34. https://doi.org/10.1177/10888683211054897

Mabry PL, Olster DH, Morgan GD, Abrams DB (2008) Interdisciplinarity and systems science to improve population health: a view from the NIH Office of Behavioral and Social Sciences Research. Am J Prev Med 35: S211–224. doi: 10.1016/j.amepre.2008.05.018

Rutter, H., Savona, N., Glonti, K., Bibby, J., Cummins, S., Finegood, D. T., & White, M. (2017). The need for a complex systems model of evidence for public health. *Lance*t, *390*(10112), 2602-2604. https://doi.org/10.1016/S0140-6736(17)31267-9

Scarapicchia, T. M. F., Amireault, S., Faulkner, G., & Sabiston, C. M. (2017). Social support and physical activity participation among healthy adults: A systematic review of prospective studies. *International Review of Sport and Exercise Psychology*, *10*, 50–83.

Stevens, M., Rees, T., Coffee, P., Steffens, N. K., Haslam, A., & Polman, R. (2017). A social identity approach to understanding and promoting physical activity. *Sports Medicine*, *47*, 1911-1918.

Zolfaghari, M., Meshkovska, B., Banik, A., Kamphuis, C. B. M., Kopainsky, B., Luszczynska, A., Murrin, C., & Lien, N. (2022). Applying a systems perspective to understand the mechanisms of the European School Fruit and Vegetable Scheme. *European Journal of Public Health*, *32*(S4), iv107–iv113. https://doi.org/10.1093/eurpub/ckac054

You will be able to leave your belongings in the room during lunch and coffee breaks and the room will be locked. You will NOT be able to leave your belongings, including laptops, overnight.

We are looking forward to welcoming you in Bremen!

Expert Meeting Programme and Activities

All times are in Central European Summer Time (CEST).

2nd September 2023: Welcome Drinks Reception at 8:00 PM, city centre.
On Saturday, we will meet at 8:00 PM at a bar on a beautiful street, called 'Schlachte', for the Welcome Reception (28195 Bremen, Germany). Members of the Synergy Board and the facilitators will be there to meet you. Drinks and snacks will be provided. More information on the name and location of the bar will be shared closer to the meeting.

3rd Sept 2023: Day One of the Expert Meeting at the Institute for Public Health and Nursing Science, Grazer Str. 2, 28359 Bremen, Germany.
On Sunday, We will meet at 8:30 AM in the Institute for Public Health and Nursing Science, for the registration (map and entrance photo on page 8). Please don't forget your laptop/tablet. There will be signage in the university on the day. More information on the reception and EM room location will be shared closer to the meeting.

Lunch (Vegan hot lunches) and two refreshment breaks (hot and cold drinks, and snacks) will be provided on both the Sunday and the Monday.

Sunday guided walk – We will meet at 6:00 PM in Market square, under the statue of ROLAND, to begin the guided walking tour of the city. The walk will end at the restaurant where we will be having the dinner.

Sunday Dinner – Dinner is provided on the Sunday after the guided walk. We will be at the restaurant at 7:30 PM. If you are not taking part in the walking tour, meet us at the restaurant at 7:30 PM.

Lunches, refreshments, a drink and snacks on the Saturday, and the Sunday dinner have been covered by your registration fee.

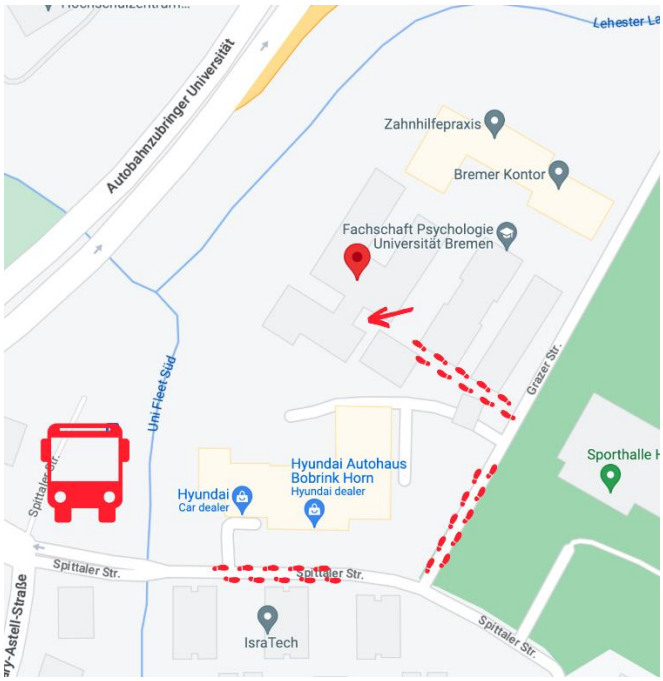
Program Day 1: Sunday, 3rd September 2023

Time:	**Activity:**
08:30 – 09:00	Synergy registration
09:00 – 10:30	Welcome and the plan for the expert meeting
	Speed dating: getting to know each other better
	Introduction to system mapping, complex system approach *and social environment of physical activity*
10:30 – 11:00	*Coffee break*
11:00 – 11:45	System mapping, part 1: identifying key social determinants of physical activity
11:45 – 12:30	System mapping, part 2. Identifying connections between determinants
12:30 – 13:30	*Lunch*
13:30 – 15:00	System mapping, part 3: checking the proposed loops in the causal loop diagram, identifying if any loops/connections are missing
15:00 – 15:30	*Coffee break*
15:30 – 16:15	Final revisions of the system map of social determinants of physical activity
16:15 – 16:30	Summary of Day 1
18:00 – 19:30	Guided city walk
19:30 onwards	Group dinner

Program Day 2: Monday, 4th September 2023

Time:	Activity:
09:00 – 09:30	Introduction to *social environment and sedentary behaviors*
09:30 – 10:30	System mapping, part 1: identifying key social determinants of sedentary behavior
10:30 – 11:00	*Coffee break*
11:00 – 11:45	System mapping, part 2. Identifying connections between determinants
11:45 – 12:30	System mapping, part 3: checking the proposed loops in the causal loop diagram, identifying if any loops/connections are missing
12:30 – 13:30	*Lunch*
14:00 – 15:00	Final revisions of the system map of social determinants of sedentary behavior
15:00 – 15:30	*Coffee break + Workshop evaluation*
15:30 – 16:00	Summary of Day 2 and further steps

EM directions



Practical Information

Venues: The following link on the conference website has a map showing all important locations and tram routes connecting them: https://2023.ehps.net/venue/

Power supplies: All power sockets in Bremen have a standard voltage of 230V with a standard frequency of 50hz. Sockets and plugs are of type F, which is the standard type in Germany. This socket also works with plug C and E if they have an additional pinhole.

Climate: Bremen has a temperate maritime climate, characterized by mild temperatures and moderate rainfall throughout the year. The average daily temperature in August is around 20°C (68°F), with highs of 25°C (77°F) and lows of 15°C (59°F). Summers are generally mild, and it's advisable to carry a light jacket for the evenings. Rainfall is distributed fairly evenly throughout the year, so carrying a small foldable umbrella is recommended.

Currency: The official currency in Bremen, as in the rest of Germany, is the Euro. ATMs are widespread, especially in the city center. Credit and debit card payments are accepted in many places, but it's always a good idea to carry some cash for smaller establishments or unexpected needs.

Language: The official language is German. While a significant portion of the population speaks German as their mother tongue, many residents are also fluent in English, especially in the city areas. Other commonly spoken languages include Turkish, Russian, and Arabic due to the diverse population.

Public Transport: Bremen is an easy city to get around. Almost any city accommodation will connect you to public transport, which is frequent and comfortable.

- **Operating Hours**: Public transport typically starts around 5:00 am and runs until midnight, with night buses available for late-night travelers.
- **Tickets**: Tickets can be purchased at stations, on trams / buses, online, or via mobile apps. Remember to validate your ticket before boarding. The cost varies based on the duration and zones covered.

- **Airport Connectivity**: Bremen Airport is well-connected to the city center (tram line 6, direction "Universität", duration: appr. 15 minutes). Taxis and ride-sharing services like Uber are also available.
- **Venue Connectivity**: From the central station, you can take tram line 6 in the direction of "Universität" directly to the university campus. The tram stop "Universität-Zentralbereich" is located right in front of the university's main entrance. Trams on line 6 operate at regular intervals throughout the day, making it a convenient choice for transportation.
- **City Center Connectivity**: take tram line 6 in the direction of "Flughafen" from the "Universität-Zentralbereich" stop or central station. This will take you directly to the city center (stop "Domsheide"), where you can explore the historic Schnoor Quarter, Bremen Cathedral, and the popular "Marktplatz".

Taxis: Taxis are readily available in Bremen. While you can hail a taxi on the street, it's often cheaper to book one in advance (e.g., calling the "Taxi Ruf" +49 421 14 0 14) or use a ride-sharing app. Popular apps like Uber and Bolt operate in Bremen, offering convenient transportation options.
For more detailed information on transportation, local attractions, and other travel-related queries, please visit the official Bremen tourism website.

Contact for Synergy

If you need to get in touch with one of our Synergy Board Members during the Expert Meeting and related events, here are our contact numbers:

- Lauren: +447969085393 or email lauren.gatting@kcl.ac.uk
- Sinéad: +32456156970 or email moyletts@tcd.ie
- In case of a 'local emergency', you can contact Melita Rolandi-Strati (Easy Conferences): 0035 7 995 20000

We are looking forward to seeing you in Bremen!
Synergy 2023 Organising Board

Supplemental File 2

Recommended changes to PA systems map

1) Amalgamate "Inclusive Gender Norms" and "Inclusive Cultural Norms" to "Inclusive Gender and Cultural Norms" **Rationale:** The constructs have the same antecedents and consequences so the they can be simplified to a single construct for clarity. **Results of vote:** 16/16 (100%) supported the change.

2) Extend "peer pressure" to "norms outside the nuclear family" **Rationale:** The change would extend coverage of norms beyond peers and include all sources of normative influence. This should streamline the model and provide some uniqueness to a focus on internal and external nuclear/core family systems. **Results of vote:** 15/16 (94%) supported the change.

3) Extend "educational staff supporting PA" to "Support external to the nuclear family" **Rationale:** The change would extend coverage of social support practices beyond educational staff and include all sources of support. This should streamline the model and provide some uniqueness to a focus on internal and external nuclear/core family systems. **Results of vote:** 15/15 (100%) (1 abstention) supported the change.

4) Relabel "family PA identity" to "family values and priorities" Rationale: The change in label retains the basic antecedents of an identity but is more inclusive of the motives of a family (i.e., identity is a more specific construct). **Results of vote:** 16/16 (100%) supported the change.

5) Remove health status from the model. **Rationale:** This may be conceptualized as an individual-level variable contributing within the system at a different level. Specifically, health status manifests into the social environment through factors like social support and social networks, socioeconomic position and income inequalities, discrimination, etc. Moreover, it is difficult to situate this variable using the Haughton McNeill' et al.'s taxonomy as the context. **Results of vote:** 16/16 (100%) supported the change.

6) Modify "average family education level" to "family SES" and amalgamate with "family income". **Rationale:** The relabelling will broaden the concept to be more inclusive of social status and income (in addition to education), thus aligning well with key social environment factors while reducing the number of factors in the model. **Results of vote:** 16/16 (100%) supported the change.

7) Remove "other PA identities" from the model. **Rationale:** The new "norms outside the nuclear family" and "Support external to the nuclear family" can act as proxies for this more specific variable of identity. **Results of vote:** 14/15 (100%) (1 abstention) supported the change.

8) Question for the group: Remove "Competing family values and priorities"? **Rationale:** Is this just the opposite of "family PA values and priorities?" Does it hold any intervention focus that would be independent? **Results of vote:** 10/14 (2 abstained) (71%) supported the change.

9) "Eliminate community network for practical support". **Rationale:** Not sure how this is different from Inclusiveness of community infrastructure and programs, Affordability/payment flexibility of community infrastructure and programs, Solidarity in interests, values, shared resources and activities among the community, and Support external to the nuclear family. We have content coverage of this concept through these other constructs. **Results of vote:** 16/16 (100%) supported the change.

10) Relabeled "flexible working hours" to "Flexibility in roles, duties and responsibilities". **Rationale:** to broaden the concept to other care responsibilities and external obligations. **Results of vote:** 15/16 (94%) supported the change.

11) Delete "Alignment of sleep/wake cycles". **Rationale:** The concept is a mediator between "Flexibility in duties and responsibilities" and "shared modes/co-activity". While there is nothing wrong with the concept, we can simplify our model by eliminating it because it has no other links. **Results of vote:** 16/16 (100%) supported the change.

12) Modify "family stability" with "low family entropy". **Rationale:** The term is aligned with family psychology and I believe it encompasses the broad concept of stability. **Results of vote:** 15/16 (94%) supported the change, but majority opinion was to change entropy to cohesion and organization to simplify to more straightforward language.

13) Remove "physical accessibility". **Rationale:** The term is represented in the larger concept of "Inclusiveness of community infrastructure and programs." Physical accessibility is a construct that is representing physical environment (or individual-level perceptions of it) rather than social environment. **Results of vote:** 16/16 (100%) supported the change.

14) Delete "Responsiveness of family members to PA needs". **Rationale:** I'm not sure how this manifests itself independent of the various supports (informational, encouragement, co-activity, logistical, etc). It might align more with the family psychology term of competence, but should already be manifest in these supports? **Results of vote:** 14/14 (2 abstentions) (100%) supported the change.

15) Relabel "family roles" to "regulatory support" **Rationale:** The concept of regulatory support represents roles, rules, and standards so it is the actionable component of the role concept in terms of health behaviors. **Results of vote:** 16/16 (100%) supported the change.

16) Modify "visibility of PA within the community" to "descriptive norm". Rationale: The concept is well-represented in social literature with this term. **Results of vote:** 16/16 (100%) supported the change.

17) Remove "fit between family structure and PA needs". **Rationale:** this is a highly specific construct with limited utility within the model. The concept is likely represented by the different supports and family variables. **Results of vote:** 16/16 (100%) supported the change.

Supplemental File 3

Paths model for the Determinants of the Moderate-to-Vigorous Intensity Physical Activity Family Social Environment

Construct	→ Path	Comments (positive effect unless indicated otherwise)
Inclusiveness of community infrastructure and programs	Inclusive gender and cultural norms in community	Original path **Result of Vote: 16/16 support**
	Descriptive PA norm in community	Original path **Result of Vote: 16/16 support**
	Social norms external to the nuclear family	Proposed path **Result of Vote: 16/16 support**
	Support external to the nuclear family	Proposed path **Result of Vote: 16/16 support**
	Informational support in family/community	Proposed path **Result of Vote: 16/16 support**
	Family aggregation of regular physical activity	Proposed path **Result of Vote: 16/16 support**
Inclusive gender and cultural norms in community	Inclusiveness of community infrastructure and programs	Original path **Result of Vote: 16/16 support**
	Social norms external to the nuclear family	Original path **Result of Vote: 16/16 support**
	Family PA values and priorities	Original path **Result of Vote: 16/16 support**
	Negative social control by family /community members	Proposed path (-?) **Result of Vote: 16/16 support** Support is for - path
	Descriptive PA norm in community	Proposed path **Result of Vote: 16/16 support**
Social norms external to the nuclear family	Inclusive gender and cultural norms in community	Original path **Result of Vote: 15/16 support**

	Inclusiveness of community infrastructure and programs	Proposed path **Result of Vote: 15/16 support**
	Family PA values and priorities	Proposed path **Result of Vote: 16/16 support**
	Negative social control by family /community members	Proposed path (-?) **Result of Vote: 16/16 support** Support is for a - path
	Descriptive PA norm in community	Proposed path **Result of Vote: 16/16 support**
Support external to the nuclear family	Social norms external to the nuclear family	Original path **Result of Vote: 15/16 support**
	Informational support in family/community	Original path **Result of Vote: 16/16 support**
	Descriptive PA norm in community	Original path **Result of Vote: 16/16 support**
	Social reward form family/community members	Original path **Result of Vote: 16/16 support**
	Verbal encouragement from family/ community members	Original path **Result of Vote: 15/16 support**
	Family PA values and priorities	Proposed path **Result of Vote: 16/16 support**
	Family logistical support	Proposed path **Result of Vote: 15/16 support**
Affordability/payment flexibility of community infrastructure and programs	Inclusiveness of community infrastructure and programs	Original path **Result of Vote: 16/16 support**
	Descriptive PA norm in community	Proposed path **Result of Vote: 16/16 support**
	Social norms external to the nuclear family	Proposed path **Result of Vote: 15/16 support**
Family PA values and priorities	Family PA modeling	Original path **Result of Vote: 16/16 support**

	Verbal encouragement from family/ community members	Original path **Result of Vote: 16/16 support**
	Family logistical support	Original path **Result of Vote: 16/16 support**
	Negative social control by family /community members	Original path (-) **Result of Vote: 16/16 support** Support was for a negative path
	Social reward from family/community members	Original path **Result of Vote: 16/16 support**
	Informational support in family/community	Original path **Result of Vote: 16/16 support**
	Home physical environment	Original path **Result of Vote: 15/16 support**
	Regulatory support in the family	Original path **Result of Vote: 16/16 support**
	Family connectedness and engagement in the community	Proposed path **Result of Vote: 13/16 support**
	Shared mode/co-activity in family	Proposed path **Result of Vote: 16/16 support**
	Family cohesion and organization (low entropy)	Proposed path **Result of Vote: 16/16 support**
Family SES	Informational support in family/community	Original path **Result of Vote: 15/16 support**
	Flexibility in roles, duties and responsibilities of family members	Original path **Result of Vote: 16/16 support**
	Affordability/payment flexibility of community infrastructure and programs	Original path Comment: not sure if there should be a causal pathway from family SES to this variable; I would propose to delete it **Result of Vote: 15/16 support** **Support to delete the path**

	Family logistical support	Original path **Result of Vote: 15/16 support**
	Home physical environment	Original path **Result of Vote: 15/16 support**
	Physical environment safety in community	Original path **Result of Vote: 13/16 support**
	Interpersonal safety in family and community	Proposed path **Result of Vote: 9/16 support** Path not supported
	Inclusiveness of community infrastructure and programs	Proposed path **Result of Vote: 7/16 support** Path not supported
	Social norms external to the nuclear family	Proposed path **Result of Vote: 8/16 support** Path not supported
	Descriptive PA norm in community	Proposed path **Result of Vote: 9/16 support** Path not supported
Family connectedness and engagement in the community	Interpersonal safety in family and community	Original path Comment: delete? Might this be the other way around? **Result of Vote: 8/16 support** Path stands
	Informational support in family/community	Proposed path **Result of Vote: 16/16 support**
	Social reward from family/community members	Proposed path **Result of Vote: 16/16 support**
	Support external to the nuclear family	Proposed path **Result of Vote: 16/16 support**
Family PA modeling	Family PA values and priorities	Original path **Result of Vote: 16/16 support**
	Social reward from family/community members	Original path Comment: I am unsure about this path. Not

		sure of the basis. Parallel processes. Delete? **Result of Vote: 16/16 support** Delete path
	Family logistical support	Proposed path **Result of Vote: 13/16 support**
Home physical environment	Family PA values and priorities	Original path Comment: I think the relationship is the other way around but I guess there is some evidence for environmental restructuring. **Result of Vote: 14/16 support** Support to delete path
	Family PA modeling	Proposed path **Result of Vote: 16/16 support**
	Shared mode/co-activity in family	Proposed path **Result of Vote: 16/16 support**
Informational support in family/community	Affordability/payment flexibility of community infrastructure and programs	Original path Comment: I am not sure this path is necessary. Delete? **Result of Vote: 16/16 support** **Support to delete path**
	Family PA values and priorities	Proposed path **Result of Vote: 14/16 support**
Shared mode/co-activity in family	Family PA modeling	Original path **Result of Vote: 16/16 support**
	Family PA values and priorities	Original path **Result of Vote: 15/16 support**
	Social reward from family/community members	Original path **Result of Vote: 16/16 support**

	Negative social control by family /community members	Proposed path Comment: Acknowledges there are negative aspects to this in some cases, especially adolescents wo may desire PA autonomy from family? **Result of Vote: 15/16 support**
	Family cohesion and organization (low entropy)	Proposed path **Result of Vote: 14/16 support**
	Verbal encouragement from family/ community members	Proposed path **Result of Vote: 16/16 support**
	Regulatory support in family	Proposed path **Result of Vote: 15/16 support**
Flexibility in roles, duties and responsibilities of family members	Family PA modeling	Original path **Result of Vote: 10/16 support** Path not supported
	Shared mode/co-activity in family	Original path **Result of Vote: 14/16 support**
	Family logistical support	Original path **Result of Vote: 16/16 support**
	Family PA values and priorities	Proposed path **Result of Vote: 9/16 support** **Path not supported**
	Family cohesion and organization (low entropy)	Proposed path **Result of Vote: 15/16 support**
	Social reward from family/community members	Proposed path **Result of Vote: 4/16 support** Path not supported
Family logistical support	Family PA values and priorities	Proposed path **Result of Vote: 12/16 support**
	Social reward from family/community members	Proposed path **Result of Vote: 15/16 support**

	Shared mode/co-activity in family	Proposed path **Result of Vote: 16/16 support**
Size of family network	Family logistical support	Original path **Result of Vote: 16/16 support**
	Informational support in family/community	Original path **Result of Vote: 16/16 support**
	Flexibility in roles, duties and responsibilities of family members	Proposed path **Result of Vote: 15/16 support**
Negative social control by family /community members	Family cohesion and organization (low entropy)	Proposed path (-) **Result of Vote: 15/16 support**
	Interpersonal safety in family and community	Proposed path (-) **Result of Vote: 16/16 support**
Family cohesion and organization (low entropy)	Verbal encouragement from family/ community members	Original path **Result of Vote: 16/16 support**
	Shared mode/co-activity in family	Original path **Result of Vote: 15/16 support**
	Negative social control by family /community members	Original path (-) **Result of Vote: 14/16 support**
	Family logistical support	Proposed path **Result of Vote: 15/16 support**
	Social reward from family/community members	Proposed path **Result of Vote: 15/16 support**
Interpersonal safety in family and community	Family connectedness and engagement in the community	Original path **Result of Vote: 15/16 support**
	Family cohesion and organization (low entropy)	Proposed path **Result of Vote: 13/16 support**
Verbal encouragement from family/ community members	Social reward from family/community members	Proposed path **Result of Vote: 16/16 support**
Social reward from family/community members	Family PA modeling	Original path Comment: this likely makes sense in a feedback loop but I think modeling is more

		purposeful than just engagement in PA (I.E., it's a demonstration of a behavior for promotion of another). We might want to cut this path **Result of Vote: 16/16 support** Support is to cut the path
	Family PA values and priorities	Original path **Result of Vote: 16/16 support**
	Shared mode/co-activity in family	Original path Comment: same argument as modeling. We might delete this path… **Result of Vote: 16/16 support** Support is to delete the path
Regulatory support in family	Family PA values and priorities	Original path **Result of Vote: 16/16 support**
	Family logistical support	Original path **Result of Vote: 16/16 support**
	Family cohesion and organization (low entropy)	Proposed path **Result of Vote: 15/16 support**
Physical environment safety in community	Descriptive PA norm in community	Original path **Result of Vote: 15/16 support**
	Family connectedness and engagement in the community	Proposed path **Result of Vote: 15/16 support**
Descriptive PA Norm in community	Physical environment safety in community	Original path **Result of Vote: 13/16 support**
	Social norms external to the nuclear family	Proposed path **Result of Vote: 16/16 support**
	Family PA values and priorities	Proposed path **Result of Vote: 16/16 support**

Node Name	In degree	Out degre	Degree	Page rank	Betweenn	Closeness	Eigenvecto
Affordability/payment fle	0	3	3	0.7	0	0.4	0.07
Descriptive PA norm in co	6	3	9	2.5	17.4	0.55	0.18
Family PA modeling	3	2	5	4.2	0.3	0.48	0.16
Family PA values and prio	10	11	21	21.3	74.6	0.72	0.43
Family SES	0	5	5	0.7	8.6	0.48	0.11
Family aggregation of reg	1	0	1	0.9	0	0.34	0.02
Family cohesion and orga	6	5	11	7.6	14.4	0.55	0.29
Family connectedness an	3	3	6	4.1	10.6	0.54	0.17
Family logistical support	8	3	11	7.1	22.1	0.61	0.3
Flexibility in roles duties and responsibilities of family members	2	3	5	1	4.3	0.46	0.15
Home physical environme	2	2	4	2.4	1.8	0.48	0.14
Inclusive gender and cultu	2	5	7	1.2	5.3	0.52	0.15
Inclusiveness of communi	3	6	9	1.4	28.5	0.5	0.14
Informational support in f	6	1	7	4.2	19.7	0.57	0.16
Interpersonal safety in far	1	2	3	2.8	1.2	0.44	0.09
Negative social control by	5	2	7	5	10.8	0.52	0.2
Physical environment safe	2	2	4	1.5	4.3	0.45	0.06
Regulatory support in fam	2	3	5	3.1	0	0.49	0.18
Shared mode/co-activity i	5	7	12	6.9	11.5	0.56	0.31
Size of family network	0	3	3	0.7	1.4	0.43	0.08
Social norms external to t	5	5	10	2.2	14.7	0.55	0.2
Social reward from family	7	1	8	11.8	2.8	0.56	0.27
Support external to the n	2	7	9	2	18.8	0.62	0.28
Verbal encouragement fr	4	1	5	4.7	0.6	0.5	0.21
	85	85					

or centrality

Supplemental File 5. Feedback loops (with at least 3 variables in the loop) identified in the restricted physical activity system map

No.	Feedback loops description – all loops are reinforcing the system[a]
1	Descriptive PA norm in community (+) Social norms external to the nuclear family (+) Inclusiveness of community infrastructure and programs (+) Support external to the nuclear family (+) Descriptive PA norm in community
2	Family PA values and priorities (+) Family connectedness and engagement in the community (+) Support external to the nuclear family (+) Descriptive PA norm in community (+) Family PA values and priorities
3	Family PA values and priorities (+) Family connectedness and engagement in the community (+) Support external to the nuclear family (+) Descriptive PA norm in community (+) Social norms external to the nuclear family (+) Family PA values and priorities
4	Family PA values and priorities (+) Family connectedness and engagement in the community (+) Support external to the nuclear family (+) Family logistical support (+) Family PA values and priorities
5	Family PA values and priorities (+) Family connectedness and engagement in the community (+) Support external to the nuclear family (+) Family logistical support (+) Shared mode/co-activity in family (+) Family PA values and priorities
6	Family PA values and priorities (+) Family connectedness and engagement in the community (+) Support external to the nuclear family (+) Family logistical support (+) Shared mode/co-activity in family (+) Social reward from family/community members (+) Family PA values and priorities
7	Family PA values and priorities (+) Family connectedness and engagement in the community (+) Support external to the nuclear family (+) Family logistical support (+) Social reward from family/community members (+) Family PA values and priorities
8	Family PA values and priorities (+) Family connectedness and engagement in the community (+) Support external to the nuclear family (+) Family PA values and priorities
9	Family PA values and priorities (+) Family connectedness and engagement in the community (+) Support external to the nuclear family (+) Social norms external to the nuclear family (+) Inclusiveness of community infrastructure and programs (+) Descriptive PA norm in community (+) Family PA values and priorities
10	Family PA values and priorities (+) Family connectedness and engagement in the community (+) Support external to the nuclear family (+) Social norms external to the nuclear family (+) Descriptive PA norm in community (+) Family PA values and priorities
11	Family PA values and priorities (+) Family connectedness and engagement in the community (+) Support external to the nuclear family (+) Social norms external to the nuclear family (+) Family PA values and priorities
12	Family PA values and priorities (+) Family connectedness and engagement in the community (+) Support external to the nuclear family (+) Social reward from family/community members (+) Family PA values and priorities
13	Family PA values and priorities (+) Family logistical support (+) Shared mode/co-activity in family (+) Family PA values and priorities
14	Family PA values and priorities (+) Family logistical support (+) Shared mode/co-activity in family (+) Social reward from family/community members (+) Family PA values and priorities

No.	Feedback loops description – all loops are reinforcing the system[a]
15	Family PA values and priorities (+) Family logistical support (+) Social reward from family/community members (+) Family PA values and priorities
16	Family PA values and priorities (+) Family logistical support (+) Social reward from family/community members (+) Family PA values and priorities
17	Family PA values and priorities (+) Shared mode/co-activity in family (+) Social reward from family/community members (+) Family PA values and priorities
18	Family PA values and priorities (+) Family connectedness and engagement in the community (+) Social reward from family/community members (+) Family PA values and priorities
19	Inclusiveness of community infrastructure and programs (+) Descriptive PA norm in community (+) Social norms external to the nuclear family (+) Inclusiveness of community infrastructure and programs

Note: (+) represents a positive effect

Figure xx

Variables in the restricted physical activity system map

Legend

Blue color gradient: Darker gradient indicates higher closeness; Circle shape – larger circle indicates higher betweenness; Solid arrows represent positive direction of the association; Dashed arrows indicate negative direction of the association

Supplemental File 6

Recommended changes to SB systems map

1) Relabel "work/school requiring digital connection at home" to "Flexibility in roles, duties and responsibilities". **Rationale:** to broaden the concept to other care responsibilities and external obligations across the family. This is inclusive of work/school duties. **Results of vote:** 13/16 (81%) supported the change.

2) Modify "average family education level" to "family SES" and amalgamate with "family income". **Rationale:** The relabeling will broaden the concept to be more inclusive of social status and income (in addition to education), thus aligning well with key social environment factors while reducing the number of factors in the model. **Results of vote:** 16/16 (100%) supported the change.

3) Remove "environmental qualities" from the model. **Rationale:** The concept has an unclear link to the social environment and appears better suited as a purely physical environment concept. **Results of vote:** 16/16 (100%) supported the change.

4) Replace "practical support" with the term "logistical support". **Rationale:** The change keeps the terminology similar to prior literature and consistency in language across the PA and SB models. **Results of vote:** 16/16 (100%) supported the change.

5) Remove "healthy family lifestyle" from the model. **Rationale:** The concept describes a behavior rather than a social environment process". The social environment variables that may better attend to this concept are descriptive, cultural, and injunctive norms, which are already in the model. **Results of vote:** 16/16 (100%) supported the change.

6) Relabel "emotional support" to "Interpersonal safety in family and community". **Rationale:** The concept aligns with the label used in our PA model and is broader than, but inclusive of, emotional support for changes in SB. **Results of vote:** 8/15 (1 abstention) (53%) supported the change. Emotional support was retained because it was deemed different from interpersonal safety.

7) Amalgamate "strategy allowing child SB," "using SB as a reward," "family rules for limiting screen time" and "monitoring" with the term "regulatory support". **Rationale:** The term regulatory support aligns with the social support and parenting literature on setting and enforcing family rules. The terms used in our version one of the model are inclusive of regulatory support practices. Regulatory support is also representing a similar level of generality as logistical support or interpersonal safety in family and community. **Results of vote:** 16/16 (100%) supported the change.

8) Relabel "environmental qualities (indoors)" to "home physical environment". **Rationale:** The term is congruent with the PA model and inclusive of affordances that facilitate the social environment for SB. **Results of vote:** 16/16 (100%) supported the change.

9) Remove "poor health status" from the model. **Rationale:** This may be conceptualized as an individual-level variable contributing within the system at a different level. Specifically, health status manifests into the social environment through factors like social support and social networks, socioeconomic position and income inequalities, discrimination, etc. Moreover, it is difficult to situate this variable using the Haughton McNeill' et al.'s taxonomy as the context. **Results of vote:** 16/16 (100%) supported the change.

10) Replace "family values to limit SB" with "competing family values and priorities". **Rationale**: The concept aligns with our PA model and highlights how other, opposing values, may curtail a behavior. In this case values and priorities other than SB would facilitate the limiting of SB time. **Results of vote:** 16/16 (100%) supported the change.

11) Replace "SB affordances to built environment" with "community physical environment". **Rationale:** The concept is identical but the altered term better separates community from home environment in the model. **Results of vote:** 16/16 (100%) supported the change.

12) Relabel/replace "raising awareness of SB in the family" to "informational support in family/community". **Rationale:** Raising awareness is an individual factor; modifying the label to informational support positions the concept as a social environment concept. The change to family and community makes informational support more inclusive. **Results of vote:** 16/16 (100%) supported the change.

13) Modify "Cultural Norms" to "Inclusive Gender and Cultural Norms in family and community" **Rationale:** The concept is now similar in label to the PA model. It had been broadened to include gender and to specify inclusiveness both in the family system and broader community. **Results of vote:** 16/16 (100%) supported the change.

14) Remove "parental PA". **Rationale:** The concept is a behavior. The social environment process is better addressed in the model through modelling. **Results of vote:** 16/16 (100%) supported the change.

15) Remove "neighborhood cohesion". **Rationale:** the concepts of descriptive and injunctive norms external to the nuclear family are already included in the model and account for much of this concept already. **Results of vote:** 10/13 (3 abstentions) (77%) supported the change.

16) 16) Question for the group: Remove "competing family values and priorities" (see point #10 for change to label)? **Rationale:** Is this just the opposite of "Family interest in SB activities?" Does it hold any intervention focus that would be independent? **Results of vote:** 9/13 (3 abstentions) (69%) supported the change.

17) Add "shared SB". **Rationale:** We include this concept as a form of social support in the PA model and it seems equally relevant to SB activities. **Results of vote:** 16/16 (100%) supported the change.

18) Add "low family entropy". **Rationale:** We include this concept in the PA model and it seems equally relevant to SB activities. Many SB activities are easy to engage in and can be solitary (for example, videogaming) and thus the behavior could be a result of family entropy. **Results of**

vote: 16/16 (100%) supported the change, but majority opinion was to change entropy to cohesion to simplify to more straightforward language.

Supplemental File 7

Path model for the Determinants of the Sedentary Behavior Family Social Environment

Construct	→ Path	Comments (positive effect unless indicated otherwise)
Flexibility in roles, duties and responsibilities of family members	Regulatory support	Original path **Result of Vote: 16/16 support**
	Family logistical support	Suggested path **Result of Vote: 16/16 support**
	Dog ownership	Suggested path **Result of Vote: 10/16 support** **Path not supported**
	Shared chores and home environment workload among family members	Suggested path **Result of Vote: 16/16 support**
	Shared SB in the family	Suggested path **Result of Vote: 7/16 support** **Path not supported**
	Family cohesion and organization (low entropy)	Suggested path **Result of Vote: 14/16 support**
Availability of passive transportation		Comment: No linkages. **Result of Vote: 9/9 support**
Family SES	Family logistical support	Original path **Result of Vote: 16/16 support**
	Flexibility in roles, duties and responsibilities of family members	Original path **Result of Vote: 15/16 support**
	Physical environment safety in community	Original path **Result of Vote: 15/16 support**
	Home physical environment	Original path **Result of Vote: 16/16 support**
	Community physical environment	Original path **Result of Vote: 16/16 support**
	Availability of passive transportation	Original path **Result of Vote: 16/16 support**
	Informational support in family/community	Original path **Result of Vote: 16/16 support**
Family logistical support	Shared chores and home environment workload among family members	Suggested path **Result of Vote: 15/16 support**
	Family cohesion and organization (low entropy)	Suggested path **Result of Vote: 15/16 support**
	Verbal encouragement from family/ community members	Suggested path **Result of Vote: 12/16 support**
Regulatory support in family	Negative social control by family /community members	Original path

		Comment: delete path because these are likely parallel **Result of Vote: 16/16 support** Delete path
	Verbal encouragement from family/ community members	Original path **Result of Vote: 15/16 support**
	Descriptive norms external to the nuclear family	Original path Comment: suggest we delete **Result of Vote: 16/16 support** Delete path
	Injunctive norms external to the nuclear family	Original path Comment: suggest we delete **Result of Vote: 16/16 support** Delete path
	Home physical environment	Suggested path **Result of Vote: 10/16 support** **Path not supported**
	Shared chores and home environment workload among family members	Suggested path **Result of Vote: 16/16 support**
	Family cohesion and organization (low entropy)	Suggested path **Result of Vote: 15/16 support**
Home physical environment	Family interest in SB activities	Original path (-) Comment: Agree with the path, not sure about the polarity. I think it is a +? **Result of Vote: 16/16 support** **Path included as +**
	Regulatory support in family	Suggested path **Result of Vote: 13/16 support**
	Family SB modeling	Suggested path **Result of Vote: 16/16 support**
	Negative social control by family /community members	Suggested path **Result of Vote: 7/16 support** **Path not supported**
	Shared SB in the family	Suggested path **Result of Vote: 16/16 support**
Community physical environment	Physical environment safety in community	Original path **Result of Vote: 15/16 support**
	Family logistical support	Suggested path **Result of Vote: 9/16 support** **Path not supported**
	Dog ownership	Suggested path **Result of Vote: 8/16 support** **Path not supported**
	Descriptive norms external to the nuclear family	Suggested path **Result of Vote: 16/16 support**

Dog ownership	Shared chores and home environment workload among family members	Original path **Result of Vote: 11/16 support**
	Family logistical support	Suggested path **Result of Vote: 8/16 support** **Path not supported**
	Emotional support	Suggested path Comment: this might be a stretch but there is convincing therapy evidence that dogs lighten a household emotionally **Result of Vote: 14/16 support**
	Regulatory support in family	Suggested path **Result of Vote: 8/16 support** **Path not supported**
	Family cohesion and organization (low entropy)	Suggested path **Result of Vote: 13/16 support**
Physical environment safety in community	Family logistical support	Suggested path **Result of Vote: 11/16 support**
	Community physical environment	Suggested path **Result of Vote: 16/16 support**
	Dog ownership	Suggested path **Result of Vote: 9/16 support** **Path not supported**
	Inclusive gender and cultural norms in family/community	Suggested path **Result of Vote: 10/16 support** **Path not supported**
	Descriptive norms external to the nuclear family	Suggested path **Result of Vote: 15/16 support**
Family interest in SB activities	Regulatory support in family	Original path (-) **Result of Vote: 16/16 support**
	Family SB modeling	Original path **Result of Vote: 16/16 support**
	Family logistical support	Suggested path (-) **Result of Vote: 16/16 support**
	Home physical environment	Suggested path **Result of Vote: 16/16 support**
	Informational support in family/community	Suggested path (-) **Result of Vote: 16/16 support**
	Verbal encouragement from family/ community members	Suggested path (-) **Result of Vote: 16/16 support**
	Shared SB in the family	Suggested path **Result of Vote: 16/16 support**
	Dog ownership	Suggested path (-) **Result of Vote: 10/16 support** **Path not supported**
Family SB modeling	Family interest in SB activities	Original path

		Result of Vote: 15/16 support
	Descriptive norms external to the nuclear family	Original path Comment: suggest we delete **Result of Vote: 16/16 support** Path deletion supported
	Shared SB in the family	Suggested path **Result of Vote: 15/16 support**
Informational support in family/community	Regulatory support in family	Original path **Result of Vote: 16/16 support**
	Family interest in SB activities	Original path (-) **Result of Vote: 16/16 support**
	Family logistical support	Suggested path **Result of Vote: 16/16 support**
	Home physical environment	Suggested path (-) **Result of Vote: 16/16 support** Note this support is for a negative path
	Family SB modeling	Suggested path (-) **Result of Vote: 16/16 support** Note this support is for a negative path
	Verbal encouragement from family/ community members	Suggested path **Result of Vote: 16/16 support**
	Shared SB in the family	Suggested path (-) **Result of Vote: 16/16 support**
Negative social control by family /community members	Informational support in family/community	Original path Comment: delete – parallel process? **Result of Vote: 16/16 support** **Support is to delete the path**
	Home physical environment	Suggested path (-) **Result of Vote: 10/16 support** **Path not supported**
	Shared chores and home environment workload among family members	Suggested path **Result of Vote: 11/16 support**
	Verbal encouragement from family/ community members	Suggested path (-) **Result of Vote: 16/16 support**
	Family cohesion and organization (low entropy)	Suggested path (-) **Result of Vote: 16/16 support**
Shared chores and home environment workload among family members	Family cohesion and organization (low entropy)	Suggested path **Result of Vote: 14/16 support**
Inclusive gender and cultural norms in family/community	Descriptive norms external to the nuclear family	Original path **Result of Vote: 16/16 support**
	Family SB modeling	Original path **Result of Vote: 10/16 support**

		Path not supported
	Shared chores and home environment workload among family members	Original path (-) **Result of Vote: 14/16 support**
	Family interest in SB activities	Original path Comment: not convinced we need this link **Result of Vote: 12/16 support** Support to delete the link
	Flexibility in roles, duties and responsibilities of family members	Suggested path **Result of Vote: 16/16 support**
	Emotional support	Suggested path **Result of Vote: 15/16 support**
	Verbal encouragement from family/ community members	Suggested path **Result of Vote: 11/12 support (4 did not answer)**
	Family cohesion and organization (low entropy)	Suggested path **Result of Vote: 14/15 support (1 did not answer)**
Injunctive norms external to the nuclear family	Family SB modeling	Original path **Result of Vote: 16/16 support**
	Family interest in SB activities	Original path **Result of Vote: 15/16 support**
	Flexibility in roles, duties and responsibilities of family members	Suggested path **Result of Vote: 15/16 support (**
	Informational support in family/community	Suggested path (-) **Result of Vote: 14/16 support**
	Community physical environment	Suggested path **Result of Vote: 13/16 support**
Descriptive norms external to the nuclear family	Regulatory support in family	Original path (-) Comment: Maybe, but it likely seems it would affect family interest in SB, which would then affect regulatory support. Delete. **9/16 supported the path** **Support to delete the path**
	Family interest in SB activities	Original path (-) **Result of Vote: 16/16 support**
Verbal encouragement from family/ community members	Informational support in family/community	Original path **Result of Vote: 15/16 support**
	Emotional Support	Suggested path **Result of Vote: 16/16 support**
	Family cohesion and organization (low entropy)	Suggested path **Result of Vote: 16/16 support**
Shared SB in the family	Family interest in SB activities	Suggested path

		Result of Vote: 16/16 support
	Family SB modeling	Suggested path **Result of Vote: 15/16 support**
	Family cohesion and organization (low entropy)	Suggested path **Result of Vote: 13/16 support**
Family cohesion and organization (low entropy)	Family logistical support	Suggested path **Result of Vote: 16/16 support**
	Emotional support	Suggested path **Result of Vote: 16/16 support**
	Regulatory support in family	Suggested path **Result of Vote: 16/16 support**
	Informational support in family/community	Suggested path **Result of Vote: 15/16 support**
	Negative social control by family /community members	Suggested path (-) **Result of Vote: 16/16 support**
	Shared chores and home environment workload among family members	Suggested path **Result of Vote: 15/16 support**
	Verbal encouragement from family/ community members	Suggested path **Result of Vote: 16/16 support**
	Shared SB in the family	Suggested path **Result of Vote: 12/16 support**

Node Name	In degree	Out	Degree	Page			
Availability of passive	1	0	1	1.1	0	0.36	0.03
Community physical	3	2	5	1.8	3.4	0.44	0.08
Descriptive norms	3	1	4	2.4	6.7	0.51	0.1
Dog ownership	0	3	3	1	0.3	0.42	0.11
Emotional support	4	0	4	5.8	1.1	0.46	0.14
Family SB modeling	5	2	7	6.1	0.9	0.48	0.18
Family SES	0	7	7	1	27.3	0.56	0.19
Family cohesion and	9	8	17	17	37.4	0.65	0.36
Family interest in SB	6	7	13	9.6	15.8	0.61	0.3
Family logistical support	6	3	9	5.8	19.1	0.63	0.3
Flexibility in roles duties	3	4	7	1.4	13.1	0.61	0.25
Home physical	3	4	7	3.1	4.4	0.53	0.22
Inclusive gender and	0	6	6	1	9.7	0.54	0.2
Informational support in	5	7	12	6.8	18.5	0.67	0.36
Injunctive norms external	0	5	5	1	6.4	0.51	0.17
Negative social control	1	3	4	2.8	0.1	0.43	0.13
Physical environment	2	3	5	1.9	3.7	0.48	0.1
Regulatory support in	5	3	8	5.8	5.8	0.56	0.29
Shared SB in the family	5	3	8	8	5.3	0.53	0.2
Shared chores and home	7	1	8	7.6	6.7	0.56	0.23
Verbal encouragement	7	3	10	9	12.2	0.59	0.3

Supplemental File 9. Feedback loops (including at least 3 variables) identified in the restricted system map of determinants of sedentary behaviors

No.		Feedback loops description[a]
1	R	Family cohesion and organization (low entropy) (+) Family logistical support (+) Verbal encouragement from family/community members (+) Family cohesion and organization (low entropy)
2	R	Family cohesion and organization (low entropy) (+) Family logistical support (+) Verbal encouragement from family/community members (+) Informational support in family/community (-)⇢ Family interest in SB activities (-)⇢ Regulatory support in family (+) Family cohesion and organization (low entropy)
3	B	Family cohesion and organization (low entropy) (+) Family logistical support (+) Verbal encouragement from family/community members (+) Informational support in family/community (-)⇢ Family interest in SB activities (+) Shared SB in the family (+) Family cohesion and organization (low entropy)
4	B	Family cohesion and organization (low entropy) (+) Family logistical support (+) Verbal encouragement from family/community members (+) Informational support in family/community (-)⇢ Shared SB in the family (+) Family cohesion and organization (low entropy)
5	R	Family cohesion and organization (low entropy) (+) Family logistical support (+) Verbal encouragement from family/community members (+) Informational support in family/community (-)⇢ Shared SB in the family (+) Family interest in SB activities (-)⇢ Regulatory support in family (+) Family cohesion and organization (low entropy)
6	R	Family cohesion and organization (low entropy) (+) Family logistical support (+) Verbal encouragement from family/community members (+) Informational support in family/community (+) Regulatory support in family (+) Family cohesion and organization (low entropy)
7	R	Family cohesion and organization (low entropy) (+) Informational support in family/community (-)⇢ Family interest in SB activities (-)⇢ Family logistical support (+) Family cohesion and organization (low entropy)
8	R	Family cohesion and organization (low entropy) (+) Informational support in family/community (-)⇢ Family interest in SB activities (-)⇢ Family logistical support (+) Verbal encouragement from family/community members (+) Family cohesion and organization (low entropy)
9	R	Family cohesion and organization (low entropy) (+) Informational support in family/community (-)⇢ Family interest in SB activities (-)⇢ Regulatory support in family (+) Family cohesion and organization (low entropy)
10	R	Family cohesion and organization (low entropy) (+) Informational support in family/community (-)⇢ Family interest in SB activities (-)⇢ Regulatory support in family (+) Verbal encouragement from family/community members (+) Family cohesion and organization (low entropy)

No.		Feedback loops description[a]
11	R	Family cohesion and organization (low entropy) (+) Informational support in family/community (-)⇢ Family interest in SB activities (-)⇢ Verbal encouragement from family/community members (+) Family cohesion and organization (low entropy)
12	B	Family cohesion and organization (low entropy) (+) Informational support in family/community (-)⇢ Family interest in SB activities (+) Shared SB in the family (+) Family cohesion and organization (low entropy)
13	B	Family cohesion and organization (low entropy) (+) Informational support in family/community (-)⇢ Shared SB in the family (+) Family cohesion and organization (low entropy)
14	R	Family cohesion and organization (low entropy) (+)Informational support in family/community (-)⇢ Shared SB in the family (+) Family interest in SB activities (-)⇢ Family logistical support (+) Family cohesion and organization (low entropy)
15	R	Family cohesion and organization (low entropy) (+) Informational support in family/community (-)⇢ Shared SB in the family (+) Family interest in SB activities (-)⇢ Family logistical support (+) Verbal encouragement from family/community members (+) Family cohesion and organization (low entropy)
16	R	Family cohesion and organization (low entropy) (+) Informational support in family/community (-)⇢ Shared SB in the family (+) Family interest in SB activities (-)⇢ Regulatory support in family (+) Family cohesion and organization (low entropy)
17	R	Family cohesion and organization (low entropy) (+) Informational support in family/community (-)⇢ Shared SB in the family (+) Family interest in SB activities (-)⇢ Regulatory support in family (+) Verbal encouragement from family/community members (+) Family cohesion and organization (low entropy)
18	R	Family cohesion and organization (low entropy) (+) Informational support in family/community (-)⇢ Shared SB in the family (+) Family interest in SB activities (-)⇢ Verbal encouragement from family/community members (+) Family cohesion and organization (low entropy)
19	R	Family cohesion and organization (low entropy) (+) Informational support in family/community (+) Family logistical support (+) Family cohesion and organization (low entropy)
20	R	Family cohesion and organization (low entropy) (+) Informational support in family/community (+) Family logistical support (+) Verbal encouragement from family/community members (+) Family cohesion and organization (low entropy)
21	R	Family cohesion and organization (low entropy) (+) Informational support in family/community (+) Regulatory support in family (+) Verbal encouragement from family/community members (+) Family cohesion and organization (low entropy)

No.		Feedback loops description[a]
22	R	Family cohesion and organization (low entropy) (+) Informational support in family/community (+) Regulatory support in family (+) Family cohesion and organization (low entropy)
23	R	Family cohesion and organization (low entropy) (+) Informational support in family/community (+) Verbal encouragement from family/community members (+) Family cohesion and organization (low entropy)
24	R	Family cohesion and organization (low entropy) (+) Regulatory support in family (+)Verbal encouragement from family/community members (+) Informational support in family/community (-)⇢ Family interest in SB activities (-)⇢ Family logistical support (+) Family cohesion and organization (low entropy)
25	B	Family cohesion and organization (low entropy) (+) Regulatory support in family (+) Verbal encouragement from family/community members (+) Informational support in family/community (-)⇢ Family interest in SB activities (+) Shared SB in the family (+) Family cohesion and organization (low entropy)
26	B	Family cohesion and organization (low entropy) (+) Regulatory support in family (+) Verbal encouragement from family/community members (+) Informational support in family/community (-)⇢ Shared SB in the family (+) Family cohesion and organization (low entropy)
27	R	Family cohesion and organization (low entropy) (+) Regulatory support in family (+) Verbal encouragement from family/community members (+) Informational support in family/community (-)⇢ Shared SB in the family (+) Family interest in SB activities (-)⇢ Family logistical support (+) Family cohesion and organization (low entropy)
28	R	Family cohesion and organization (low entropy) (+) Regulatory support in family (+) Verbal encouragement from family/community members (+) Informational support in family/community (+) Family logistical support (+) Family cohesion and organization (low entropy)
29	R	Family cohesion and organization (low entropy) (+) Regulatory support in family (+) Verbal encouragement from family/community members (+) Family cohesion and organization (low entropy)
30	B	Family cohesion and organization (low entropy) (+) Shared SB in the family (+) Family interest in SB activities (-)⇢ Family logistical support (+) Family cohesion and organization (low entropy)
31	B	Family cohesion and organization (low entropy) (+) Shared SB in the family (+) Family interest in SB activities (-)⇢ Family logistical support (+) Verbal encouragement from family/community members (+) Family cohesion and organization (low entropy)
32	B	Family cohesion and organization (low entropy) (+) Shared SB in the family (+) Family interest in SB activities (-)⇢ Family logistical support (+) Verbal encouragement from family/community members (+) Informational support in family/community (+) Regulatory support in family (+) Family cohesion and organization (low entropy)

No.		Feedback loops description[a]
33	B	Family cohesion and organization (low entropy) (+)□ Shared SB in the family (+)□ Family interest in SB activities (-)⇢ Informational support in family/community (+)□ Family logistical support (+)□ Family cohesion and organization (low entropy)
34	B	Family cohesion and organization (low entropy) (+)□ Shared SB in the family (+)□ Family interest in SB activities (-)⇢ Informational support in family/community (+)□ Family logistical support (+)□ Verbal encouragement from family/community members (+)□ Family cohesion and organization (low entropy)
35	B	Family cohesion and organization (low entropy) (+)□ Shared SB in the family (+)□ Family interest in SB activities (-)⇢ Informational support in family/community (+)□ Regulatory support in family (+)□ Family cohesion and organization (low entropy)
36	B	Family cohesion and organization (low entropy) (+)□ Shared SB in the family (+)□ Family interest in SB activities (-)⇢ Informational support in family/community (+)□ Regulatory support in family (+)□ Verbal encouragement from family/community members (+)□ Family cohesion and organization (low entropy)
37	B	Family cohesion and organization (low entropy) (+)□ Shared SB in the family (+)□ Family interest in SB activities (-)⇢ Informational support in family/community (+)□ Verbal encouragement from family/community members (+)□ Family cohesion and organization (low entropy)
38	B	Family cohesion and organization (low entropy) (+)□ Shared SB in the family (+)□ Family interest in SB activities (-)⇢ Regulatory support in family (+)□ Family cohesion and organization (low entropy)
39	B	Family cohesion and organization (low entropy) (+)□ Shared SB in the family (+)□ Family interest in SB activities (-)⇢ Regulatory support in family (+)□ Verbal encouragement from family/community members (+)□ Family cohesion and organization (low entropy)
40	B	Family cohesion and organization (low entropy) (+)□ Shared SB in the family (+)□ Family interest in SB activities (-)⇢ Regulatory support in family (+)□ Verbal encouragement from family/community members (+)□ Informational support in family/community (+)□ Family logistical support (+)□ Family cohesion and organization (low entropy)
41	B	Family cohesion and organization (low entropy) (+)□ Shared SB in the family (+)□ Family interest in SB activities (-)⇢ Verbal encouragement from family/community members (+)□ Family cohesion and organization (low entropy)
42	B	Family cohesion and organization (low entropy) (+)□ Shared SB in the family (+)□ Family interest in SB activities (-)⇢ Verbal encouragement from family/community members (+)□ Informational support in family/community (+)□ Family logistical support (+)□ Family cohesion and organization (low entropy)

No.		Feedback loops description[a]
43	B	Family cohesion and organization (low entropy) (+) Shared SB in the family (+) Family interest in SB activities (-)⇢ Verbal encouragement from family/community members (+) Informational support in family/community (+) Regulatory support in family (+) Family cohesion and organization (low entropy)
44	R	Family cohesion and organization (low entropy) (+) Verbal encouragement from family/community members (+) Informational support in family/community (-)⇢ Family interest in SB activities (-)⇢ Family logistical support (+) Family cohesion and organization (low entropy)
45	R	Family cohesion and organization (low entropy) (+) Verbal encouragement from family/community members (+) Informational support in family/community (-)⇢ Family interest in SB activities (-)⇢ Regulatory support in family (+) Family cohesion and organization (low entropy)
46	B	Family cohesion and organization (low entropy) (+) Verbal encouragement from family/community members (+) Informational support in family/community (-)⇢ Family interest in SB activities (+) Shared SB in the family (+) Family cohesion and organization (low entropy)
47	R	Family cohesion and organization (low entropy) (+) Verbal encouragement from family/community members (+) Informational support in family/community (-)⇢ Shared SB in the family (+) Family interest in SB activities (-)⇢ Family logistical support (+) Family cohesion and organization (low entropy)
48	R	Family cohesion and organization (low entropy) (+)Verbal encouragement from family/community members (+) Informational support in family/community (-)⇢ Shared SB in the family (+) Family interest in SB activities (-)⇢ Regulatory support in family (+) Family cohesion and organization (low entropy)
49	R	Family cohesion and organization (low entropy) (+) Verbal encouragement from family/community members (+) Informational support in family/community (+) Family logistical support (+) Family cohesion and organization (low entropy)
50	R	Family cohesion and organization (low entropy) (+) Verbal encouragement from family/community members (+) Informational support in family/community (+) Regulatory support in family (+) Family cohesion and organization (low entropy)
51	R	Informational support in family/community (-)⇢ Family interest in SB activities (-)⇢ Family logistical support (+) Verbal encouragement from family/community members (+) Informational support in family/community
52	R	Informational support in family/community (-)⇢ Family interest in SB activities (-)⇢ Regulatory support in family (+) Verbal encouragement from family/community members (+) Informational support in family/community
53	R	Informational support in family/community (-)⇢ Family interest in SB activities (-)⇢ Verbal encouragement from family/community members (+) Informational support in family/community

No.		Feedback loops description[a]
54	B	Informational support in family/community **(-)⇢** Shared SB in the family **(+)** Family cohesion and organization (low entropy) **(+)** Verbal encouragement from family/community members **(+)** Informational support in family/community
55	R	Informational support in family/community **(-)⇢** Shared SB in the family **(+)** Family interest in SB activities **(-)⇢** Family logistical support **(+)** Verbal encouragement from family/community members **(+)** Informational support in family/community
56	R	Informational support in family/community **(-)⇢** Shared SB in the family **(+)** Family interest in SB activities **(-)⇢** Informational support in family/community
57	R	Informational support in family/community **(-)⇢** Shared SB in the family **(+)** Family interest in SB activities **(-)⇢** Regulatory support in family **(+)** Verbal encouragement from family/community members **(+)** Informational support in family/community
58	R	Informational support in family/community **(-)⇢** Shared SB in the family **(+)** Family interest in SB activities **(-)⇢** Verbal encouragement from family/community members **(+)** Informational support in family/community
59	R	Informational support in family/community **(+)** Family logistical support **(+)** Verbal encouragement from family/community members **(+)** Informational support in family/community
60	R	Informational support in family/community **(+)** Regulatory support in family **(+)** Verbal encouragement from family/community members **(+)** Informational support in family/community

Note: (+) represents a positive effect; (-)⇢ represents a negative effect; R – reinforcing feedback loop; B – a balancing feedback loop

Figure xx

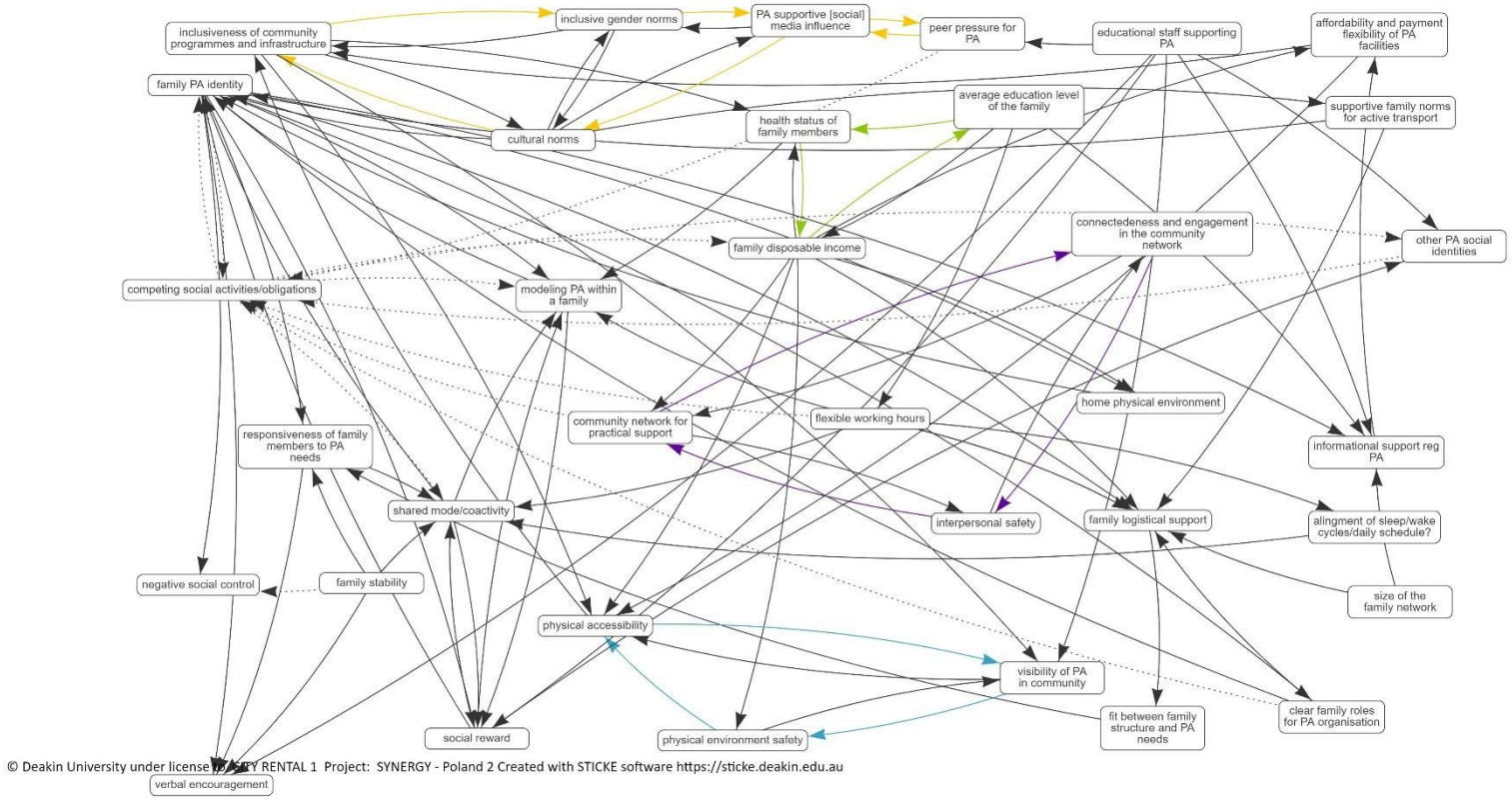
Variables in the restricted map of determinants of sedentary behavior

Legend

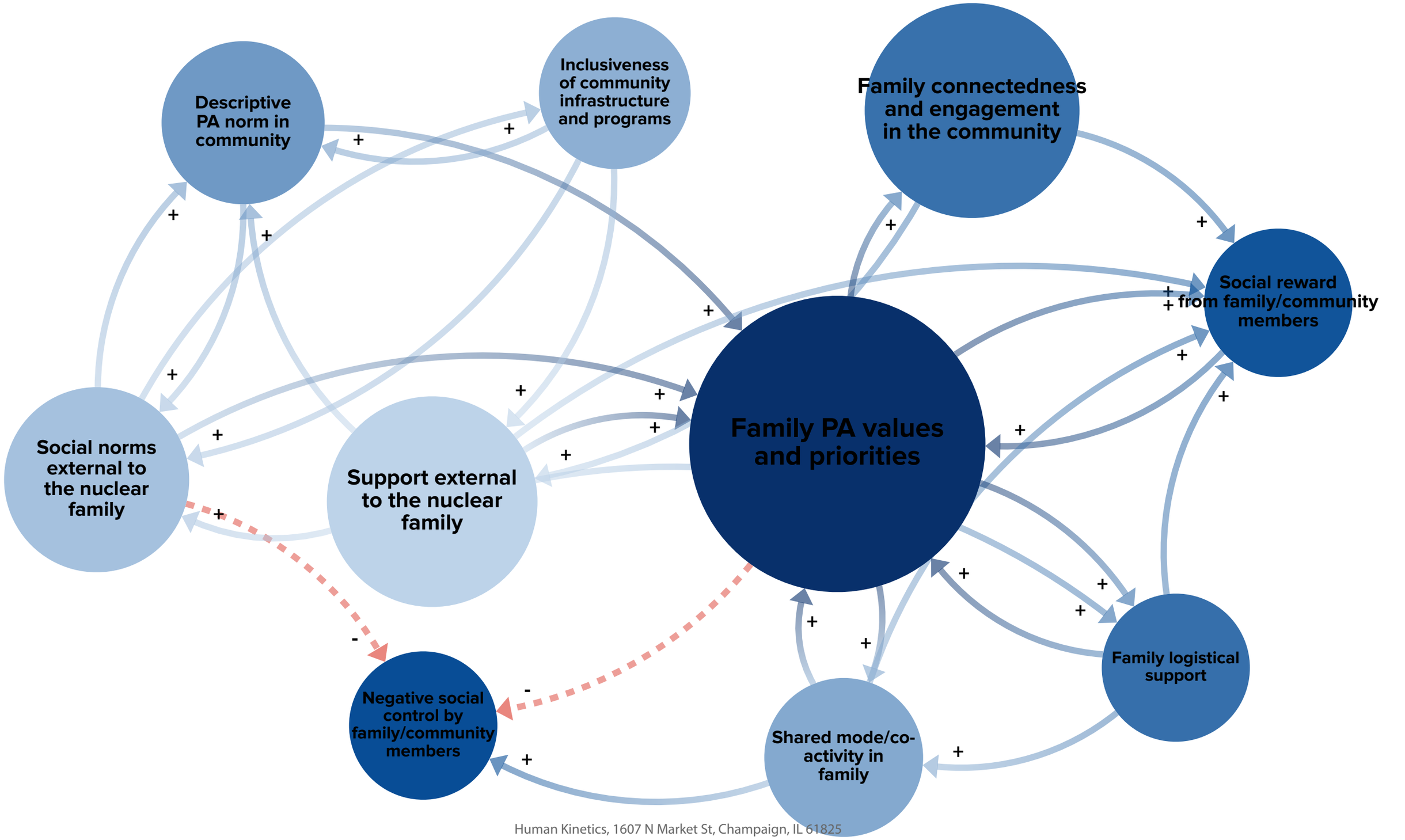
Blue color gradient: Darker gradient indicates higher closeness; Circle shape – larger circle indicates higher betweenness; Solid arrows represent positive direction of the association; Dashed arrows indicate negative direction of the association

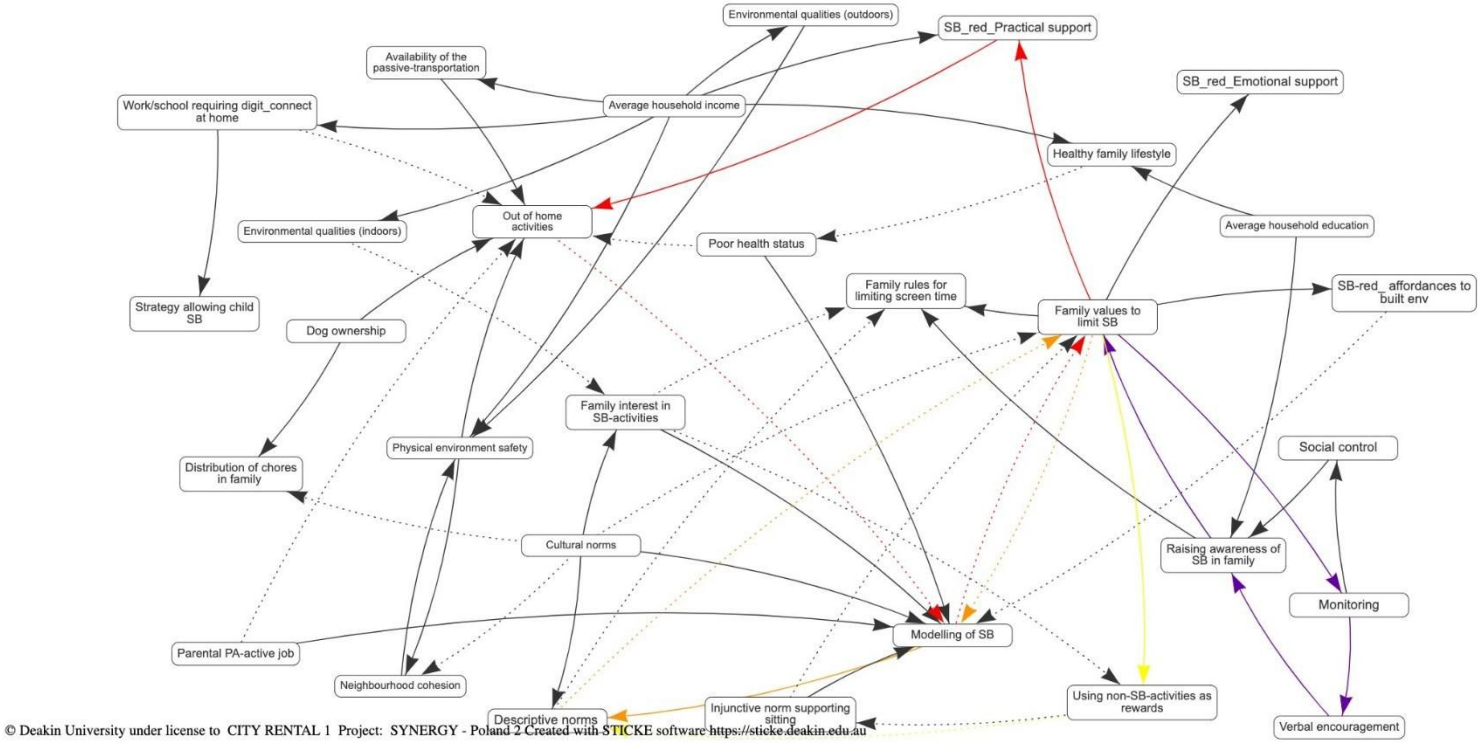
Additional Figure 2 legend

Green color gradient – darker gradient indicates higher closeness
Circle shape – larger circle indicates higher betweenness
Solid arrow – indicates positive direction of the association
Dashed arrow – indicates negative direction of the association

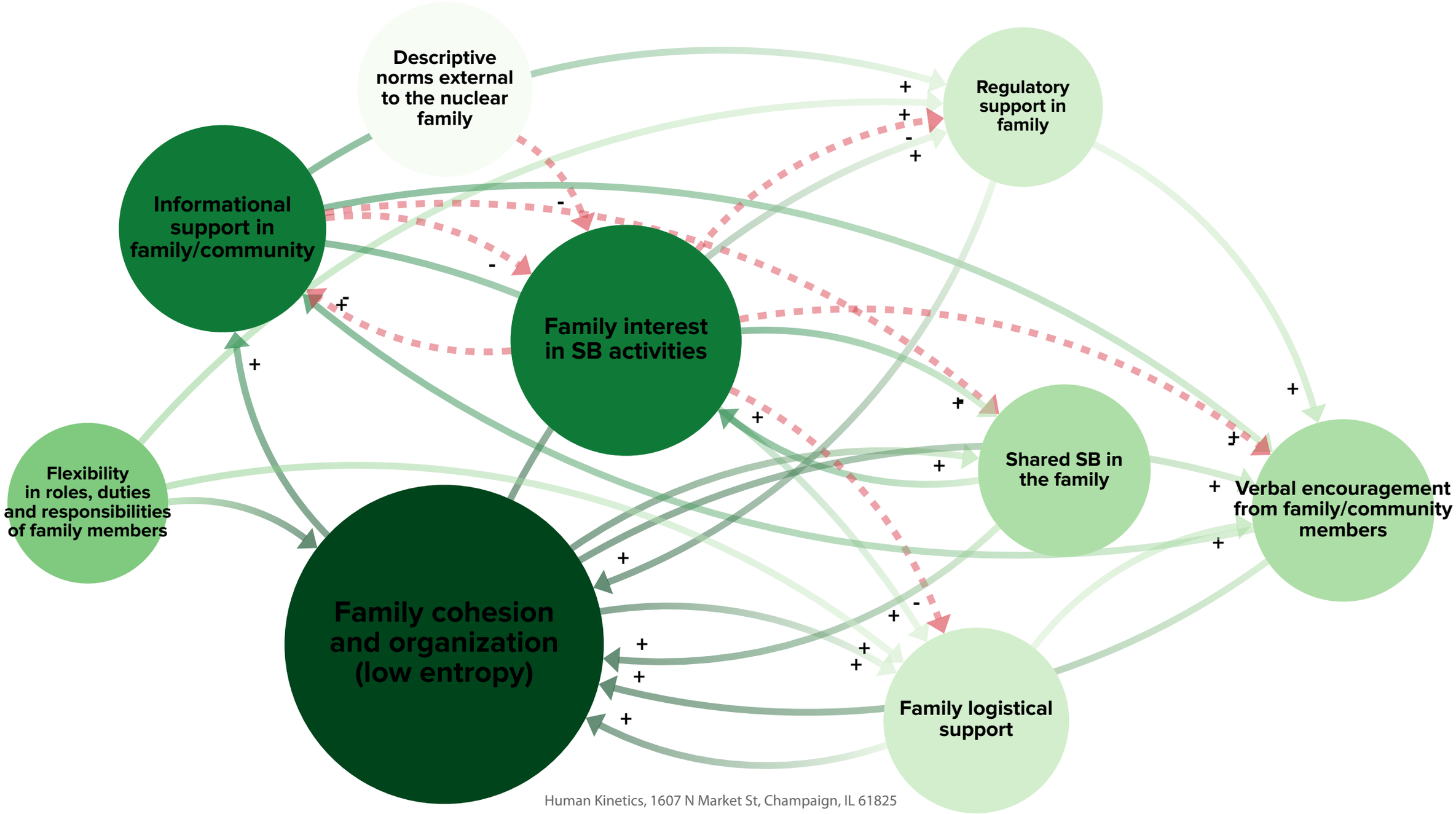


Network analysis for this original PA systems map indicated 4 determinants, characterized by the highest values of centrality indices: (1) family PA identity (degree =18; betweenness = 160.8; closeness = 0.57; eigenvector centrality = 0.43); (2) competing social activities or obligations (degree =11; betweenness = 107.3; closeness = 0.53; eigenvector centrality = 0.33), (3) family disposable income (degree =11; betweenness = 99.7; closeness = 0.49; eigenvector centrality = 0.21), and (4) shared mode/coactivity (degree =11; betweenness = 42.9; closeness = 0.49; eigenvector centrality = 0.33). High betweenness was also found for community network for practical support (64.0) and family logistical support (56.8).


Descriptive PA norm in community
Inclusiveness of community infrastructure and programs
Family connectedness and engagement in the community
Social reward from family/community members
Social norms external to the nuclear family
Support external to the nuclear family
Family PA values and priorities
Family logistical support
Negative social control by family/community members
Shared mode/co-activity in family
+
-



Network analysis for this original SB systems map indicated 2 determinants that were characterized by the highest values of centrality indices: (1) family values to limit SB (degree =12; betweenness = 144; closeness = 0.52; eigenvector centrality = 0.46); (2) modelling of SB (degree =10; betweenness = 97.5; closeness = 0.53; eigenvector centrality = 0.41). Additionally, out of home activities had high betweenness and closeness indicators (93.9 and 0.48, respectively), but low eigenvector (0.2), whereas descriptive norms for SB had the third highest eigenvector centrality values (0.32).


Descriptive norms external to the nuclear family
Regulatory support in family
Informational support in family/community
Family interest in SB activities
Shared SB in the family
Verbal encouragement from family/community members
Flexibility in roles, duties and responsibilities of family members
Family cohesion and organization (low entropy)
Family logistical support