An Update of the Literature Supporting the Well-Being Benefits of Plants: Part 2 Physiological Health Benefits[1]

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Abstract

This paper focused on providing evidence from the literature regarding the physiological health benefits associated with plants, thereby influencing the physiological, psychological, and cognitive well-being constructs affecting quality of life. These benefits are segmented and discussed using the following categories: better sleep, increased birthweights, decreased diabetes, decreased ocular discomfort, enhanced immunity, improved circadian functioning, improved rehabilitation, decreased cardiovascular and respiratory disease, decreased mortality, improved digestion, decreased allergies, increased physical activity, and improved cognitive development. This research should be strategically incorporated into both industry-wide and firm-specific marketing messages that highlight the quality of life value proposition in order to maintain the industry's sense of value and relevance to residential landscape consumers of the future. These findings also present evidence that municipal leaders and policymakers can use in justifying green infrastructure-related funding decisions, as well as grounds for the construction industry using biophilic design principles in ensuring the built environment offers opportunities for green space interactions. The green industry can play a pivotal role not only in providing plants of high quality for these applications but educating stakeholders regarding the benefits discussed herein.

Index words: benefits of plants, emotional health, mental health.

Significance to the Horticulture Industry

This paper is the second of a four-part series that provides a review of the substantial body of peer-reviewed research that has been conducted regarding the economic, environmental, and health and well-being benefits of green industry products and services. While the first article focused on the emotional and mental health benefits that plants provide, this article focuses specifically on the physiological health benefits provided by plants. These benefits include better sleep, increased birthweights, decreased incidence of diabetes, decreased ocular discomfort, enhanced immunity, improved circadian functioning, improved rehabilitation from illnesses, decreased likelihood of cardiovascular and respiratory disease, decreased mortality, improved digestive functioning, decreased susceptibility to allergies, and improved cognitive development. This research should be strategically incorporated into both industry-wide and firm-specific marketing messages that highlight how quality of life dimensions are affected in order to enhance the perceived value and relevance of green industry products for gardening and landscaping consumers in the future.

Introduction

In 2011, Hall and Dickson published a forum article in the Journal of Environmental Horticulture (JEH) that summarized the economic, environmental, and health and well-being benefits associated with people-plant interactions. The proposition put forth in that article was that green industry firms needed to focus on these types of functional benefits in their marketing messages to consumers rather than simply base their value proposition on the features and benefits of the plants themselves (e.g. aesthetic characteristics, insect and/or disease resistance, cold or heat tolerance, salt tolerance, drought resistance, etc.). By doing so, the end consumer would better understand the inherent ways in which plants improve the quality of their lives and begin perceiving plants to be a necessity in their lives rather than a mere luxury they could cast aside during economic downturns, as they did during the "Great Recession" of 2008-2009.

Since 2011, there has been a plethora of additional research studies conducted regarding these functional plant benefits. A total of 1,348 citations have been compiled in total and about two-thirds of those have been conducted since 2011. These voluminous studies provide compelling evidence that warrants further attention. Thus, this new series of forum articles attempts to update the findings summarized in the original article by Hall and Dickson by focusing on the research on plant benefits that has been conducted since 2011. By doing so, this new information provides the basis for even more innovative green industry marketing efforts, which, in turn, may positively influence the price elasticity of demand for plants in general.

The second topic in the four-part series, *physiological health benefits of plants*, is one that has been shown to resonate with consumers of all demographic segments (Hall and Dickson 2011). These benefits are segmented and discussed using the following categories: better sleep, increased birthweights, decreased diabetes, decreased ocular discomfort, enhanced immunity improved circadian functioning, improved rehabilitation, decreased cardiovascular and respiratory disease, decreased mortality, improved digestion, decreased allergies, increased physical activity, and improved cognitive development.

Many of these benefits can be experienced during exposure to plants in both the built environment and the natural environment. The built environment includes all human-made spaces in which people live, work, and play including buildings, gray infrastructure (e.g. utilities, transportation networks, etc.), and improved landscapes (outdoor landscape spaces that have been "improved"

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aesthetically). The term "green spaces" has been used extensively to refer to areas of urban vegetation including public and private parks and gardens, residential landscapes, and urban forests and other municipal landscapes. However, with urbanization and global migration into urban centers, exposure to outdoor green spaces is becoming less frequent in people's everyday life, prompting the use of biophilic design principles to offer exposure to the elements of natural environments within the built environment. For example, "green buildings" often incorporate green walls, green roofs, water features, natural lighting, and natural materials that emulate nature.

Better Sleep

Getting inadequate amounts of sleep can heighten risks for obesity, chronic disease, and mortality (Cappuccio et al. 2011, Cappuccio et al. 2008, Chaput et al. 2007, Hislop and Arber 2003, Hublin et al. 2007). Time spent in natural settings and improved landscapes can decrease multiple issues with sleep (Morita et al. 2011). For example, short sleep syndrome is less common in "greener" (e.g. more plants incorporated) residential surroundings (Astell-Burt et al. 2013). Experiencing indoor and outdoor natural environments helps transition individuals from a state of stress towards a state of relaxation and subconscious activity enabling better sleep (El-Sheikh et al. 2013), reflected by an improvement in common measures of sleep quality (Astell-Burt et al. 2013, Grigsby-Toussaint et al. 2015, Morita et al. 2011).

Birthweight

Residential greenness during pregnancy is associated with healthier birth weights and lowered risk of small-for-gestational-size infants (Dadvand et al. 2012a, Dadvand et al. 2012b, Donovan et al. 2011, Hystad et al. 2014). Birth outcomes may be influenced by noise and pollution but results from a recent study found that birth outcomes can also be heavily influenced by psychosocial and psychological factors (Nicole 2014). Positive birth outcomes were associated with "greenness thresholds" above 0.15 (scores under 0.15 are considered dense urban areas along major roadways, etc.) (Nicole 2014).

Specifically, greater exposure to plants affects birth outcomes by altering increasing maternal levels of physical activity, reducing maternal stress, enhancing social contacts among mothers, reducing maternal noise and air pollution exposure, and moderating ambient temperatures (Dadvand et al. 2012a). Studies that used birth registries to link the mother's address at birth to a measure of greenness (most commonly, the normalized difference vegetation index or NDVI), found consistent positive associations between greenness and birth weight (Agay-Shay et al. 2014, Dadvand et al. 2012a, Dadvand et al. 2014a, Hystad et al. 2014, Markevych et al. 2014).

Other studies found that higher greenness exposure was linked to lower odds of a child being small for gestational age or preterm (Hystad et al. 2014), larger head circumferences (Dadvand et al. 2012a), and lower infant mortality risk, although these findings were not replicated across all studies because some birth registry studies were not able to account for alcohol or tobacco use (Agay-Shay et al. 2014) or maternal income or education (Hystad et al. 2014). However, most analyses were able to adjust for these factors and also model complex environmental exposures including air pollution (Dadvand et al. 2012a, Hystad et al. 2014), neighborhood walkability, and noise (Hystad et al. 2014). Stronger associations between greenness and birth outcomes were observed among those whose parents had lower levels of education and lower socio-economic status (Agay-Shay et al. 2014, Dadvand et al. 2012a, Markevych et al. 2014).

Decreased Diabetes

Interacting with plants also counters the adverse effects of stress on energy metabolism, insulin secretion, inflammatory pathways (Bhasin et al. 2013), and ultimately diabetes and obesity (Astell-Burt et al. 2014, Bodicoat et al. 2014, Lachowycz and Jones 2011, Thiering et al. 2016). Walking in natural areas or improved landscapes (outdoor landscape spaces that have been "improved" aesthetically) results in healthier levels of the hormone *didehydroepiandrosterone* in the bloodstream (DHEA) (Ohtsuka 1998). DHEA has cardioprotective, anti-obesity, and anti-diabetic properties (Bjørnerem et al. 2004). Thus, regular exposure to natural areas helps protect against obesity, type 2 diabetes, hypertension, and coronary heart disease.

Even brief exposure to plants has a number of positive short-term effects, which suggests that regular nature exposure could improve diabetes outcomes significantly by stimulating the release of anti-diabetic hormones *adiponectin* and DHEA, modulating insulin by way of its effects on parasympathetic activity (Bhasin et al. 2013), and normalizing elevated blood glucose. In diabetic patients, monthly nature walks were sufficient to reduce glycated hemoglobin (HbA1c) to just below the threshold value for a diabetes diagnosis. Not surprisingly then, diabetes mellitus (Type 1 or 2) is less prevalent among individuals living in greener surroundings (Astell-Burt et al. 2014, Maas et al. 2009) and among public park users than non-park-users (Tamosiunas et al. 2014).

Decreased Ocular Discomfort

Being around plants indoors results in decreased ocular (eye) discomfort (French et al. 2013, Guggenheim et al. 2012). A cohort of sixth grade students at two newly constructed elementary schools performed a self-assessment of ocular discomfort symptoms in association with indoor air quality. While indoor plant additions made little difference in air temperature and relative humidity, the plants did stabilize levels of carbon dioxide and decreased indoor concentrations of volatile organic compounds such as toluene and xylene, which may lead to ocular discomfort. Students in classrooms without indoor plants experienced an increase in ocular discomfort symptoms, those in classrooms with indoor plants demonstrated a decrease in frequency (He et al. 2015).

Enhanced Immunity

Immunity is generally referred to as the body's ability to ward off disease or withstand infection. Recent studies show that immunity from illnesses can be enhanced by viewing, interacting with, or even being in the vicinity of plants. Kuo (2015) and Song et al. (2016) both found that being in nature improves immune function in several ways. First, consistent with the "hygiene hypothesis," contact with microbial and other antigens in natural settings during particular developmental windows may modify (improve) immune function over the lifespan (Hanski et al. 2012, Kondrashova et al. 2013, Nicolaou et al. 2005, Rook 2013, Ruokolainen et al. 2015, Stiemsma et al. 2015), perhaps operating through effects on the microbiome (Lee and Mazmanian 2010). Second, short-term exposure to natural substances (such as phytoncides from trees) have been associated with improved natural killer (NK) cell activity (Li 2010, Li and Kawada 2011, Li et al. 2008a, Li et al. 2008b, Li et al. 2006). NK cells play important protective roles against cancer, viral infections, and inflammatory cytokines that have been implicated in diabetes, cardiovascular disease, depression, and other negative health outcomes (Cesari et al. 2003, Dowlati et al. 2010, Orange and Ballas 2006, Wellen and Hotamisligil 2005).

These natural killer cells (also known as NK cells, K cells, and killer cells) are a type of lymphocyte (a white blood cell) and a component of innate immune systems. Stress recovery and immune function mechanisms may not be distinct because of reciprocal relationships between these two physiologic systems (Irwin and Cole 2011, Nusslock and Miller 2016). Fantuzzi (2013) also found that *adiponectin* levels in the body increase while in nature and improved landscapes (Li and Kawada 2011), which helps protect against atherosclerosis, acute urinary tract infections, infectious diseases of the intestinal canal, and upper respiratory tract infections.

Illnesses associated with failing immunoregulation and poorly-regulated inflammatory responses, manifested as chronically raised levels of C-reactive protein and proinflammatory cytokines, are mitigated through exposure to plant-filled nature, reducing the levels of these inflammatory cytokines (Mao et al. 2012). There is another theory that the "awe" experienced with viewing impressive landscape settings helps with immunity (Stellar et al. 2015). Regular experiences of awe are tied to healthier, lower levels of inflammatory cytokines (Stellar et al. 2015). Moreover, extended time in nature decreased inflammatory cytokines implicated in chronic disease by roughly one-half (Mao et al. 2012).

Environmental biodiversity has been proposed to contribute to human *commensal microbiota*, the "good bacteria" living on or in the human body (Rook 2013, Von Hertzen et al. 2011). Commensal microbiota play a role in the immune system's ability to tolerate rather than attack non-threats (Kuo 2013). In one study, the abundance of one particular commensal microorganism on the skin was correlated with levels of an anti-inflammatory cytokine playing a key role in immunologic tolerance (IL-10) (Hanski et al. 2012). The more access that children have to natural settings in which to play, the more proteobacteria on their skin and the more diverse their gamma-proteobacteria (Hanski et al. 2012, Ruokolainen et al. 2015).

Epidemiological studies suggest that living close to the natural environment is associated with long-term health benefits including reduced death rates, reduced cardiovascular disease, and reduced psychiatric problems (Rook 2013). This is often attributed to psychological mechanisms boosted by exercise, social interactions, and sunlight. Compared with urban environments, exposure to green spaces does indeed trigger rapid psychological, physiological, and endocrinological effects.

Improved Autonomic Nervous System and Parasympathetic Activity

The autonomic nervous system is a control system that acts largely unconsciously and regulates bodily functions such as the heart rate, digestion, respiratory rate, pupillary response, urination, and physical arousal. This system is the primary mechanism in control of the fight-or-flight response. The sympathetic nervous system is the part of the autonomic nervous system that prepares the body to react to stresses such as threat or injury. It causes muscles to contract and heart rate to increase. The parasympathetic nervous system is the part of the autonomic nervous system that controls functions of the body at rest. It helps maintain homeostasis in the body. It causes muscles to relax and heart rate to decrease.

Window views and images of green spaces in nature reduce sympathetic nervous activity and increase parasympathetic activity (Brown et al. 2013, Gladwell et al. 2012), These sympathetic and parasympathetic effects drive immune system behavior (Kenney and Ganta 2011) with long-term health consequences (van den Berg et al. 2015b). As little as five minutes of exposure to images of trees, grass, and fields in a laboratory setting is enough to increase parasympathetic nervous activity and decrease heart rate (Brown et al. 2013, Gladwell et al. 2012). Relaxation has important implications for health, and, when used regularly, relaxation techniques have documented dose-response effects on immune functioning (Kang et al. 2011). Deep states of relaxation counter the adverse effects of stress on energy metabolism, insulin secretion, and inflammatory pathways (Bhasin et al. 2013) with potential implications for diabetes, cardiovascular disease, and other inflammatory disorders. Parasympathetic dominance also appears to play an important role in sleep quality (El-Sheikh et al. 2013).

Improved Rehabilitation

Many older people in senior living facilities suffer from complex health problems (DelSesto 2017). The total effect of green spaces on self-perceived health has been shown to be positive and significant by generating a sense of being "away" from the facility, enhancing the level of interest associated with their day, and fostering an environment that encourages visitation from family and friends (Dahlkvist et al. 2016).

Field experiments in hospitals show much faster post-operative healing and a reduced need for pain medication in patients with rooms whose windows look out on trees and other elements in the landscape (Mehaffy and Salingaros 2015, Park et al. 2013). To examine the health benefits of a bedroom window view to natural surroundings, coronary and pulmonary patients were divided in half (Raanaas et al. 2012) and patients were placed either in a private bedroom with a panoramic view to natural surroundings or in a room with a view that was partially or entirely blocked by buildings. For women, a blocked view appeared to negatively influence change in physical health, whereas for men, a blocked view appeared to negatively influence change in mental health (Raanaas et al. 2012). Pulmonary patients with a panoramic view showed greater improvement in mental health than coronary patients without such a view. Those with a panoramic view to nature more often chose to stay in their bedroom when they wanted to be alone than those with a blocked view (Raanaas et al. 2012).

Lower Cardiovascular Disease Risk and Blood Pressure

Contact with nature and improved landscapes has been tied to both short- and long-term outcomes related to cardiovascular disease (Ray and Jakubec 2014). Walks in these settings have a number of positive short-term effects on the cardiovascular system by raising serum levels of adiponectin – which is antiatherogenic, and DHEA – which is cardio protective. In addition, in hypertensive patients, walks in nature decrease serum levels of a number of factors associated with high blood pressure: endothelin-1, homocysteine, renin, angiotensin II type 1 receptor, and angiotensin II type 2 receptor (Mao et al. 2012). Not surprisingly then, these walks lower blood pressure in young and middle-aged adults (Li 2010, Park et al. 2010) as well as older adults with hypertension (Mao et al. 2012). When experienced regularly, these short-term effects appear to promote cardiovascular health: individuals living in greener surroundings have lower blood pressure on average (Markevych et al. 2014a), lower rates of cardiovascular disease (Maas et al. 2009, Pereira et al. 2012, Tamosiunas et al. 2014), lower rates of cardiovascular mortality (Coutts et al. 2010, Donovan et al. 2013, Mitchell and Popham 2008, Richardson et al. 2010, Villeneuve et al. 2012), and higher survival rates after ischemic stroke (Wilker et al. 2014). A handful of studies, generally comparing larger geographical units, found a positive, but not statistically-significant relationship, between greener areas and cardiovascular outcomes (Coutts et al. 2010, Mitchell et al. 2011, Richardson et al. 2010).

The gap between the natural setting, for which our physiological functions are adapted, and the highly urbanized and artificial setting that we inhabit is a contributing cause of the "stress state" in modern people (Song et al. 2016). Walking in and viewing nature can lower blood pressure and heart rate (Brown et al. 2013, Duncan et al. 2014, Haluza et al. 2014, Markevych et al. 2014, Shanahan et al. 2016). It also can help with circulatory and heart disease risks (Maas et al. 2009). Walking in nature also increases serum levels of adiponectin (Li and Kawada 2011) and regular walks could potentially protect against obesity, type 2 diabetes, hypertension, and coronary heart disease (Song et al. 2017).

Heart rate is a significant indicator of stress response and serves as a flag for high risk of cardiovascular disease. Average heart rates of low-income African American males when walking past landscaped sites went from 103.3 beats per minute (bpm) before greening to 107.2 bpm after greening for a total increase of 3.9 bpm (South et al. 2015). When in view of non-landscaped vacant lots, average heart rate went from 99.6 bpm in the pre-intervention period to 109.1 bpm in the post-intervention period for a total increase of 9.5 bpm. The final estimate between landscaped and non-landscaped vacant lots was lower with a heart rate of $\sim$ 5.6 bpm (South et al. 2015). While the physiological effects of natural (rural and urban) environments on the cardiovascular system of coronary artery disease (CAD) patients are not fully understood, reductions in cortisol levels (a stress hormone) after outdoor walks were greater in city parks than in urban street settings (Grazuleviciene et al. 2016).

Decreased Mortality

The amount of "green" landscaped spaces in neighborhoods also has an impact on all-cause mortality (Coutts et al. 2010, Gascon et al. 2015, James et al. 2016, Mitchell et al. 2011, van den Berg et al. 2015a, Villeneuve et al. 2012). People living in neighborhoods with a higher density of trees on their streets reported significantly higher perceptions of overall health and significantly less cardio-metabolic conditions such as diabetes, high cholesterol, heart disease, and stroke. Having 10 or more trees on a city block improved health perception in ways comparable to being 7 years younger or having a higher annual personal income of $10,000 (Takano et al. 2002).

A natural experiment is an empirical study in which individuals (or clusters of individuals) are exposed to the experimental and control conditions that are determined by nature or by other factors outside the control of the investigators. A natural experiment, which provides stronger evidence of causality, was used to test whether a major change to the natural environment has influenced mortality related to cardiovascular and lower-respiratory diseases (Donovan et al. 2013). Emerald ash borer, an invasive forest pest, has caused the loss of approximately 100 million trees in the United States. Two fixed-effects regression models were used to estimate the relationship between emerald ash borer presence and county-level mortality from 1990 to 2007 in 15 U.S. states, while controlling for a wide range of demographic covariates. There was an increase in mortality related to cardiovascular and lower-respiratory-tract illness in counties infested with the emerald ash borer. The magnitude of this effect was greater as the infestation progressed and in counties with above-average median household income (Donovan et al. 2013). Across the 15 states in the study area, the loss of trees from the ash borer was associated with 6,113 deaths related to lower-respiratory-system illnesses and 15,080 cardiovascular-related deaths. These results suggest that loss of trees to the emerald ash borer (or any other cause) will increase mortality related to cardiovascular and lower-respiratory-tract illness.

Certain areas of the United States are susceptible to extreme heat events. Research have found that measures to reduce excess urban heat (known as “urban heat islands”) can have a positive impact on health during extreme heat events. One study found that a 10% increase in urban surface reflectivity (from vegetation) could reduce the number of deaths during heat events by an average of 6% (Kalkstein et al. 2013). An even larger reduction would be expected in hospital admissions from heat-related illness, although this was not a specific finding in the analysis (Kalkstein et al. 2013).

Another study examined the prospective association between residential greenness and mortality in women. In models adjusted for mortality risk factors (age, race/ethnicity, smoking, and individual- and area-level socio-economic status), women living in the highest quintile of cumulative average greenness (accounting for changes in residence during follow-up) in a 250-m area around their home had a 12% lower rate of all-cause non-accidental mortality than those in the lowest quintile (Beyer et al. 2014). These associations were strongest for respiratory- and cancer-related mortality. Policies and/or programs to increase vegetation may provide opportunities for physical activity, reduce harmful exposures, increase social engagement, improve mental health, as well as mitigate the effects of climate change.

Another study examined the association of several health outcomes with “green” housing (with various environmental amenities, including plants) and conventional low-income housing (where the prevalence of morbidities and environmental pollutants is elevated) by comparing sick building syndrome (SBS) symptoms and asthma-related morbidity among residents in multifamily units (Colton et al. 2015). Adults living in green units reported 1.35 fewer SBS symptoms annually than those living in conventional (control) homes. Furthermore, asthmatic children living in green homes experienced substantially lower incidence of asthma symptoms, asthma attacks, hospital visits, and asthma-related school absences than children living in conventional public housing (Colton et al., 2015). Other studies also validate that respiratory disease and related mortality are less prevalent in greener residential surroundings (Donovan et al. 2013, Maas et al. 2009, Richardson et al. 2010, Villeneuve et al. 2012).

Improved Pain Control

Distraction therapy with sights and sounds from natural landscapes significantly reduces pain in patients undergoing acute, painful, invasive procedures (Diette et al. 2003, Lechtzin et al. 2010). Distraction therapy can be used in addition to standard analgesic medications, especially with procedures that require only local anesthesia. Patients with chronic musculoskeletal pain who participated in horticulture therapy programs experienced better physical and mental health (Verra et al. 2012), relied less on pain medications, and also scored better on coping behavior assessments related to anxiety and pain management (Verra et al. 2012).

Obesity Reduction

Studies have found evidence tying greener residential areas with lower rates of obesity (Dadvand et al. 2014b, James et al. 2015, Lovasi et al. 2011, Michimi and Wimberly 2012, Pereira et al. 2012, Sanders et al. 2015, Wolch et al. 2011). People who live in close proximity to green spaces are three times more likely to engage in physical activity and 40% less likely to be overweight (Watson and Moore 2011). Having clean parks and nearby park access has been associated with healthier weights and greater life satisfaction amongst users. A 2014 study showed greater availability of neighborhood parks (either large or small) and greater park cleanliness to be associated with healthier weights among adults after adjusting for neighborhood features that could influence park use, such as walkability and violent crime (Stark et al. 2014).

In one study, green space was associated with a reduced likelihood of obesity among women. Another study found that street tree density was associated with lower obesity prevalence (Lovasi et al. 2013b). Individuals further from green spaces were less likely to partake in physical activity and had higher odds of obesity than those living closer (Toftager et al. 2011, Lachowycz and Jones 2011).

Residential greenness has also been tied to lower rates of obesity across the lifespan, in rural and urban environments, for multiple measures of greenness (park access, street trees, green cover, etc.) and for multiple measures of weight status [Body Mass Index (BMI), change in weight status, skin fold thickness] (Lovasi et al. 2013b, Pereira et al. 2012). Since obesity entails higher risks of other health problems including cancer, coronary heart disease, type II diabetes, and stroke (NIH 2012), regular exposure to green spaces could also potentially protect against hypertension and coronary heart disease.

Dadvand et al. (2014b) aimed to simultaneously evaluate health benefits and risks associated with different levels of greenness in children. Sedentary behavior (represented by excessive screen time) resulted in obesity, asthma, and allergic rhinoconjunctivitis (Dadvand et al. 2014b). An interquartile increase in residential surrounding greenness was associated with 11–19% lower relative prevalence of being overweight or obese (residential proximity to green spaces was defined as living within 300 m of a forest or a park). Similarly, residential proximity to green spaces was associated with a 39% decrease in excessive screen time and 25% lower incidence of obesity (Dadvand et al. 2014b).

In a study assessing community gardeners, both women and men community gardeners had significantly lower BMIs than did their neighbors who were not in the community gardening program. Significantly lower BMIs for women community gardeners compared with their sisters and men community gardeners compared with their brothers were also observed (Zick et al. 2013). Community gardeners also had lower odds of being overweight or obese than did their otherwise similar non-gardening neighbors.

Decreased Atopy (Allergies)

Growing up and living in areas with high amounts of green spaces can lead to lesser symptoms of atopy (allergies) (Dadvand et al. 2014b, Fuertes et al. 2016, Fuertes et al. 2014, Grazuleviciene et al. 2016, Kuo 2015, Lovasi et al. 2013a, Lovasi et al. 2008, Ruokolainen et al. 2015). Contact with nature, or more specifically, biodiversity, has been proposed to help the immune system learn to tolerate allergens rather than attack non-threats (Rook 2013). However, the findings on this question are extremely mixed, perhaps because vegetation has multiple effects, capturing pollutants and training the immune system on the positive side, but emitting pollen on the negative side. Multiple studies have reported that allergies, asthma, and eczema (which all reflect hypersensitivity of the immune system) are less prevalent among persons with greener residential surroundings (Fuertes et al. 2014, Hanski et al. 2012, Lovasi et al. 2008, Maas et al. 2009, Ruokolainen et al. 2015).

A few studies considered green spaces in relation to developmental outcomes and allergies in children. While beneficial effects may be mediated by physical activity, social engagement, reduced stress, and noise, heat, and air pollution reductions (Dadvand et al. 2014b), distance to the nearest green space from a child's residence was positively associated with odds of hyperactivity and inattention (Markevych et al. 2014).

Physical Activity

There is available evidence to show that there can be direct health benefits by increasing the level of physical activity on individuals of all ages (Barton et al. 2016, Broekhuizen et al. 2013, Cohen-Cline et al. 2015, Elliott 2016, Fan et al. 2011, Feda et al. 2015, Hartig and Kahn 2016, Mitchell 2013, Nielsen and Hansen 2007, Sharma-Brymer et al. 2015, Thompson Coon et al. 2011, Thompson et al. 2016, Wolf and Wohlfart 2014). A number of studies have assessed the association between green space and physical activity typically in cross-sectional analyses where neighborhood "greenness" is derived from land-use files and physical activity is ascertained by survey. In general, this evidence supports a positive association between green space and physical activity in adults (Chaix et al. 2014, Gong et al. 2014, Karusisi et al. 2012, Mytton et al. 2012, Richardson et al. 2013).

Other reviews have shown a relationship between green spaces and several determinants of health, such as physical activity and stress (CDC 2011, Bowler et al. 2010, Croucher et al. 2008, Di Nardo et al. 2012, Health Council of the Netherlands 2004, Lachowycz and Jones 2011, Lee and Maheswaran 2011, Shafer et al. 2000). Of studies that included measures of perceived greenness, one found that both subjective and objective green space were associated with walking and other forms of exercise (Sugiyama et al. 2013).

Natural surroundings such as vegetated streetscapes, parks, and schoolyards are generally associated with higher levels of physical activity in both children and adults, a plausible mechanism for many of the observed health benefits of nature contact (Bancroft et al. 2015, Bingham et al. 2016, Calogiuri and Chroni 2014, Fraser and Lock 2011, Gray et al. 2015, Hunter and Askarinejad 2015, Kaczynski and Henderson 2007, Koohsari et al. 2015, Lee et al. 2015, Shanahan et al. 2016, Stigsdotter et al. 2010, Sugiyama et al. 2014). While the mechanisms by which green surroundings might facilitate physical activity are not well understood, aesthetic preferences for green spaces may play a role (Shanahan et al. 2016). There is also a high association with green space usage and physical activity among dog owners (White et al. 2018).

For children, greenness has been associated with increased playtime outdoors (Grigsby-Toussaint et al. 2011), and in a study by Almanza et al. (2012), with higher odds of extemporaneous physical activity when in greener areas. Similar studies in children found that about half of weekend moderate–to-vigorous physical activity took place in green spaces (Lachowycz and Jones 2011), and periods of moderate–to-vigorous physical activity were significantly more likely to occur in green spaces for boys, but the relationship was positive, but not statistically significant for girls (Wheeler et al. 2010). Children and adolescents with better access to parks are less likely to have higher BMI levels (Wolch et al. 2011) and the level of children's physical activity seems to be influenced by access to parks and vegetation (Ding et al. 2011). Evidence also suggests that play in natural environments is associated with the development of fine motor skills such as balance and coordination, which in turn enable and predict physical activity (Fjørtoft 2001, Fjørtoft, 2004). The dynamic and irregular characteristics of natural play spaces may explain this observation.

Gardening has been shown to encourage people to undertake physical exercise, which in turn would contribute to improving both the physical and psychological health of gardeners (Soga et al. 2017). For older individuals, participants who spent 1 hour or more gardening per week exhibited better balance performance, fewer functional limitations, and fewer chronic conditions. Significantly fewer gardeners than non-gardeners reported a fall in a measured 2-year period (Chen and Janke 2012).

Given the concerns about low rates of physical activity among low-income minority youth, many community-based organizations are investing in the creation or renovation of public parks in order to encourage youth to become more physically active. Park improvements can have a significant impact on increasing park use and local physical activity of youth (Cohen et al. 2015). In a study assessing 11-to-13-year-old children's activity levels, the proportion of neighborhood land covered by trees and other green spaces was independently associated with the physical activity outcome, and for each additional 5% increase in the proportion of neighborhood land covered by green spaces, there was a corresponding 5% increase in the relative odds of increasing free-time physical activity outside of school hours (Janssen and Rosu 2015).

Positive Cognitive Development

Cognitive development in students (assessed as a 12-month change in the developmental trajectory of working memory and in-attentiveness) was found to be influenced by the level of greenness within and surrounding school boundaries. A high total-surrounding greenness index (including greenness surrounding student homes, commuting route, and school) was correlated with higher levels of working memory and attentiveness (Dadvand et al. 2015).

Being outdoors in natural settings also contributes to a sense of vitality or energy available for purposive action by adults (Ryan et al. 2010). Although vitality has been investigated independently of attention restoration, it is likely that vitality and attention restoration are simply different facets of a single process. The descriptions of vitality (Ryan et al. 2010) sound very much like the descriptions of "rejuvenation" and "recovery from mental fatigue" associated with attention restoration (Kuo 2015) that is enhanced by green spaces. Multiple authors have found that attention restoration, state changes in cognitive functioning, and recovery from ego-depletion are influenced by the same underlying green space mechanisms (Hofmann et al. 2012, Kaplan and Kaplan 1989, Kaplan and Berman 2010, Ryan et al. 2010).

Summary

Consumers have historically shown an inclination to purchase products that enhance their quality of life (Hall and Dickson 2011), meaning they will purchase items that positively influence their physical, psychological, cognitive, environmental, social, and spiritual well-being. Plants in natural and improved landscapes (and interiorscapes) have been documented to influence each of these quality of life constructs. This paper focused on providing evidence from the literature regarding the physiological health benefits associated with plants, thereby influencing the physiological, psychological, and cognitive well-being constructs affecting quality of life. This research should be strategically incorporated into both industry-wide and firm-specific marketing messages that highlight the quality of life value proposition in order to maintain the industry's sense of value and relevance to residential landscape consumers of the future. These findings also present evidence that municipal leaders and policymakers can use in justifying green infrastructure-related funding decisions, as well as grounds for the construction industry using biophilic design principles in ensuring the built environment offers opportunities for green space interactions. The green industry can play a pivotal role not only in providing plants of high quality for these applications but educating stakeholders regarding the benefits discussed herein.

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