# Understanding the Player-Game Relationship through Challenges and Cognitive & Motor Abilities.

**Jacques Carette**
McMaster University
Hamilton, Ontario, Canada
carette@mcmaster.ca

**Sasha Soraine**
McMaster University
Hamilton, Ontario, Canada
sorainsm@mcmaster.ca

## ABSTRACT
We explore the relationship between a player's cognitive and motor abilities, and the abilities necessary for completing specific challenges. Existing engineering-focused work does not treat the player on the same footing as the game. We view (the mechanical part of) games as a system of systems composed of the game mechanics (including challenges), and the player via their cognitive and motor abilities.

In particular, we incorporate a player model in the definition of what makes challenges the same. This allows us to define a typology of challenges and of abilities specific to games. Our motivation is to better understand the relation of abilities to the mechanical parts of players' game experiences, and thence to better craft them. For space reasons, we focus on a subset of challenges and abilities.

## CCS Concepts
**•Applied computing** → **Computer games; •Human-centered computing** → *User models; Interaction design theory, concepts and paradigms;* Interaction devices;

## Author Keywords
Gameplay challenges; player model; cognitive abilites; motor abilites; player-game relationship; competency profiles; ability configurations

## INTRODUCTION
Game design is both an artistic and engineering endeavour. From an engineering perspective, we are looking to create more *mechanically meaningful games* – where the mechanical gameplay experience is interesting for the target audience.

Our thesis is that to better engineer a mechanically meaningful game, we need a model that describes both the game and the player, and their relationship. That specific tasks can be characterized by the set of abilities needed to complete it, is called a *competency profile* [1]. To the best of our knowledge this has never been applied to games. Our long-term goal is to better tailor the gameplay to the abilities of the player. Our short-term goals for exploring this relationships are to:

1. explore novel motor experiences in games, and
2. have a method to formally discuss and categorize gameplay.

In particular, we would like to create new challenges based on under-exploited abilities.

Our aim is to systematically describe the (mechanical) player-game relationship; however, such a discussion of design choices requires a lot of space — similar work required over 300 pages to communicate their ideas [59]. Thus we present a representative part of our work. At a high level, we will present: the game, through the lens of gameplay challenges; the player, through their cognitive and motor abilities; and the relationships between them, as necessary to complete challenges (*ability configurations*).

We view our work as engineering-focused. Our contributions are: 1) a clear definition of what makes challenges "the same", 2) a framework to understand challenges via players' motor and cognitive abilities, 3) worked examples of analysing challenges and game-specific player abilities, and 4) the idea of a *limiting ability* for completion of a challenge. This work is ongoing, but the focus on particular challenges means that our presentation is self-contained. Furthermore, our extended work has not (yet) needed ideas beyond those contributed here.

## RELATED WORK

### Player-Game Relationship
Similar to Maslow's Hierarchy of Needs, we believe the player-game relationship can be viewed at a set of tiers that build upon each other, with sociological approaches (either psychographic (i.e. personality) or behavioural [21]) at the top, and lower-level mechanistic approaches at the bottom. Over the long-term, finding theories at different levels that are *coherent* with each other would be beneficial. We are interested in the lowest level, considering the ability configuration of challenges as mechanistically descriptive.

*Adaptive gaming* studies the player-game relationship to create immersive game experiences through maximizing *flow* [12, 8] or *GameFlow* [63]. The popular perspective here is behavioural modeling (top-level in our hierarchy). While quite useful in understanding how players "play" and how the high-level experience is crafted, we believe that a "low level" model is better to explore the ability configuration of challenges.

Drawing inspiration from Card et al's *Model Human Processor* [7], we look for a model which considers players as a set of interconnected subsystems, each defined by a set of abilities, that are taxed in completing tasks. We examine this relationship at its lowest level (between individual player abilities and an atomic unit of gameplay). This allows us to understand the cognitive and motor *sources* of difficulty and experience.

Zhu et al. [69] explore the player-game relation through the lens of difficulty by examining performance probability distributions of different "game events" — essentially a type of competency profile. Abstracting difficulty this way allows them to compare "game events" between games. Though performance distributions assists with comparing and describing challenge difficulty, it doesn't identify its source. They further note that having a more robust player model would help — though it would complicate event comparison, as different sources of difficulty may still produce the same distribution. We have the same goals, but wish to address those issues.

We take a similar approach, based on **challenges** and **player abilities**, and their **relation** mediated by the physicaly interactions looking at this relationship through the physical interactions between the player and the game. We seek to determine the principal *source of difficulty*. By working with interactions at the level of abilities rather than actions, we can identify when the motor or cognitive component is the *limiting factor* in challenge completion. Furthermore we can see whether one particular ability determines success, or whether other abilities can be used to improve challenge completion.

### Challenges

We found six frameworks for analysing gameplay and categorizing challenges [2, 5, 13, 15, 67, 37]. Unfortunately, we found no agreed upon definition for a challenge. By synthesizing elements of several definitions, we offer:

**Definition 2.1.** *A* challenge *is an in-game activity with a success condition which engages the player in a way that requires some level of proficiency in at least one dimension (cognitive or physical).*

The success condition can be defined by the game or the player.

We believe that a good challenge description must include:

- the in-game mechanics associated to the challenge,
- the mechanism of interaction between the player and the game (i.e. the inputs and outputs), and
- the player's mechanistic experience of the challenge.

It is through this view of challenges that we evaluate the existing work. Throughout this paper, by *player experience*, we refer solely to the motor and lower level cognitive aspects of the player. All six frameworks meet requirement 1 (as this is their purpose), but fail to address 2 or 3 properly.

Karhulahti [67] defines challenges as a goal with an uncertain outcome (which he borrows from Malone [36]). He proposes two main types: kinesthetic — where the "required nontrivial effort is at least partly psycho-motor"; and non-kinesthetic — where the "required nontrivial effort is entirely cognitive". Gameplay challenges (e.g. completing a test room in Portal) are composed of a non-kinesthetic challenge (mentally solving it) and a kinesthetic challenge (executing that solution). Though we agree that gameplay challenges may involve both types of components, this division is not fine enough.

Björk and Holopainen outline a framework to describe and analyse games, as well as a set of tools called *patterns* which are "semiformal interdependent descriptions of commonly recurring parts of the design of a game that concerns gameplay" [5]. These patterns are meant to be functional building blocks in game design, and so include elements that can define challenges (e.g. goals, actions, obstacles). Though one can combine patterns to create a list of "challenges", these do not distinguish between instances that use the same motor/cognitive components but with different importance. Though a fitting description of the mechanics of gameplay, it fails to capture the player's experience. Factors such as 2D vs 3D, camera perspective, pacing, etc, influence how the player will approach scenarios (e.g. guarding a character you can/cannot control), and thus the cognitive abilities used.

Djaouti et al created a tool for classifying and analysing gameplay mechanics called "bricks" [13]. They identified three types of bricks: play, game, and meta. *Play bricks* (manage, random, shoot, write, move, and select) are the (in-game) actions that a player can take. *Game bricks* (destroy, match, avoid, and create) are the goals of the game. Play bricks and game bricks combine to form *meta-bricks*, which describe families of challenges; e.g. the "DRIVER" meta-brick, which combines the "MOVE" and "AVOID" bricks. This tool is limited by the scope of games used to create it; they analysed 588 single player "arcade" or "casual" computer games. The types of challenges encountered in those kinds of games don't cover the scope of possible challenges that we want.

Feil and Scattergood explain challenges as defined by "objectives, and the barriers that prevent players from achieving [them]" [15], identifying six standard challenges: time, dexterity, endurance, memory/knowledge, cleverness/logic, and resource control. Though these challenges incorporate an element of the player's experience into their definitions, they are too broad to be meaningful; they defined dexterity challenges as "some sort of feat that requires dexterity". Furthermore they use the term challenge rather liberally — explaining that certain genres put more emphasis on combat, movement, or puzzle challenges.

Adams defines challenges as "any task set for the player that is non-trivial to accomplish" [2]. He presents 10 major challenge types, subdivided into 30 challenges (see Table 1). This description of challenges most closely matches our goal - as he occasionally addresses requirements two and three. This extensive list is still quite broad in its categorization: multiple gameplay instances, which are sufficiently different in play

| Type | Challenges |
|---|---|
| Physical Coordination | Speed and reaction time<br>Accuracy and precision<br>Timing and rhythm<br>Learning combination moves |
| Formal Logic | Deduction and decoding |
| Pattern Recognition | Static patterns<br>Patterns of movement and change |
| Time Pressure | Beating the clock<br>Achieving something before someone else |
| Memory & Knowledge | Trivia<br>Recollection of objects or patterns |
| Exploration Challenges | Identifying spatial relationships<br>Finding keys (unlocking any space)<br>Finding hidden passages<br>Mazes and Illogical spaces |
| Conflict | Strategy, tactics, and logistics<br>Survival<br>Reduction of enemy forces<br>Defending vulnerable items or units<br>Stealth |
| Economic | Accumulating resources or points (growth)<br>Establishing efficient production systems<br>Achieving balance or stability in a system<br>Caring for living things |
| Conceptual Reasoning | Sifting clues from red herrings<br>Detecting hidden meanings<br>Understanding social relationships<br>Lateral thinking |
| Creation & Construction | Aesthetic success(beauty or elegance)<br>Construction with a functional goal |

Table 1: Gameplay Challenges from Adams

experience, are joined together. For example, speed and reaction time challenges can describe gameplay instances ranging from quick time events, to button mashing mini-games.

McMahon et al. revise Adams' challenges, scoped down to 16 challenges [37]. Through a focus group session, they renamed several of Adams' challenges and added three new categories. We believe that Adams' list needs to be expanded rather than shortened. This condensed list confounds challenges; the "thinking outside the box" challenge is associated with the games Portal and World of Goo. However, the differences in interaction methods means that the player experience of these challenges are quite different.

### Motor Abilities

We initially explored kinesiological models of muscle groups [66, 22] and found that individual muscles can belong to multiple muscle groupings. Applying such models here would result in the same muscle groups being repeatedly activated since many different actions are controlled by the same muscles. For example, using a stylus to trace a line or a circle on can be done by bending or rotating the wrist respectively. Though these two actions are different, the muscles used are not. The distinction between actions, rather than muscles, is extremely important for video game challenges, disqualifying this model from consideration.

Developmental psychology (DevPsy) [57, 16, 46] instead focuses on normative development and acquisition of abilities and skills — an underlying assumption we share. We focus on the cognitive developmental (CD) viewpoint as (to our knowledge) it is the most concerned with motor skills. All theories from the CD view distinguish between fine and gross motor skills [57, 46]. After examining several taxonomies [], we realised that all ability lists are constructed around specific tasks, none of which applied well to a video game context. Therefore we decided to create a motor model for a video game context based on the controllers used to accomplish video game challenges.

## METHODOLOGY

To assemble this framework we compose: a model of gameplay via challenges, a model of the player via cognitive and motor abilities, and a way to analyse the relationships between them. Here we outline how these models were created.

### Gameplay Challenges

We started from Adams' list (as the most comprehensive and closest to our goal), as it fit our definition of challenge. Starting from the top of the list, we analysed challenges for their core qualities based on Adams' definitions and examples. We then added more examples that matched his descriptions, attempting to explore as many genres as we could. We then informally grouped these examples into buckets of similar gameplay based on commonalities like time limits, goals, input methods, physical movements, etc. This allowed us to differentiate some challenges that Adams considered "the same". For example, Adams' *speed and reaction time challenges* groups instances like quick time events in God of War and button mashing mini-games in Mario Party, which are very different. We then looked at each group for their commonalities, creating ad-hoc definitions of those challenges. The goal of these definitions was to capture specific **mechanical** experiences, letting us see when instances are similar or different from a player's perspective. For that, we use the following definition:

**Definition 3.1.** *Two game challenges are the same if they*

1. *involve the same motor and cognitive skills from a player,*
2. *occur over similar periods of time, and*
3. *are performance-bounded by the same skill.*

### Player Abilities

We model the player as composed of separate but connected cognitive and motor subsystems, akin to the Model Human Processor [7]. We focus on understanding the player in a mechanistic sense and so explore the motor model more fully. We use a cognitive model of three abilities (perception, attention, and memory) based on cognitive modularity [14, 68, 16].

We created our motor model by exploring the most commonly used game controllers. From these, we created a list of actions that could be classified as fine or gross motor skills. Then we moved from the level of skills to abilities by refining this list based on the motor movements necessary to enact them. We did this by examining the skills across the different controller contexts for the individual movements.

Here we focus exclusively on the fine motor abilities as they are the most common method of interaction with games due to the controller types.

### Analysis of Relationship

We analyse the relationship between challenges and abilities by identifying the abilities used when playing instances of a challenge (*ability configuration*). We characterize this relationship by assigning values to represent how important a particular ability is in completing the associated challenge. We use values in the range 1 to 100 to represent barely-used to absolutely crucial (and leave the cell blank if it is not used at all). Of course, that is much too fine, and in effect we really use a scale with five values: not used, used but not important, noticeably used, important but not limiting, and limiting factor. By *limiting factor*, we mean that challenge completion is primarily driven by the players' control over the given ability.

| Level | Range | Interpretation |
|---|---|---|
| U | 1 - 25 | Used but not important |
| N | 26 - 50 | Noticeably used |
| I | 51 - 80 | Important, but not limiting |
| L | 81 - 100 | Limiting factor |

Table 2: Ranges and what they represent

We obtain estimates for *uses* ranges by playing multiple instances of each challenge many times keeping notes as we go. We include in these notes the game, the genre of the game and the controller type, to document the diversity of evidence used. We focus in particular on the motor and cognitive abilities which were used when attempting to "win" the challenge, ordered by their relative importance (Table 2). We focus on relative importance because of subjectiveness in our measurement; nevertheless, we believe that the relative importance is indicative of interesting trends in ability configurations.

## CHALLENGES

Using this method, we divided Adams' "Speed and Reaction Time" and "Learning Combination Moves" into three families, with 18 unique challenges between them (Table 3).

| Family | Challenges |
|---|---|
| Speed | Single button input<br>Multiple button input<br>Alternating button input<br>Rapid analog stick rotation<br>Indiscriminate tapping<br>Alternating tapping<br>Rapid line drawing<br>Rapid shape drawing<br>Rapid controller shaking<br>Rapid controller rotation |
| Reaction Time | Single input<br>Multiple input<br>Motion control attacks<br>Fixed time<br>Variable time<br>Simple Reaction Time |
| Advanced Combat | Learning complex combos.<br>Attack Chaining |

Table 3: List of challenges generated from Adams' list.

We explore three of these challenges, outlining their key characteristics and providing examples from various games. These challenges were chosen to be representative of their family, as well as to showcase that challenges can be motor-dominated, or cognitive-dominated. For space reasons, we illustrate each challenge with just a few examples — we have collected an order of magnitude more than we can present.

### Speed

Speed challenges "test the player's ability to make rapid inputs on the controls" [2]. Success is determined solely by how quickly a series of inputs is made, making this a motor-dominated challenge (cognitive abilities are still used, but in a mostly trivial way). The majority of challenges in commercial games have a speed *component* — whether it is finishing a race in first place or performing a special move, both must be completed in a timely manner. The difference between a speed *component* and a speed *challenge* is the involvement of cognitive skills beyond simple perception. In contemporary video games, we have found relatively few pure speed challenges. The ones found are: button mashing, rapid analog stick rotation, rapid tapping, scribbling, rapid controller rotation, and rapid controller shaking.

#### *Button Mashing*

Button mashing (BM) is where a player must press a button or key as quickly as possible. This can be subdivided into three types of input: single, multiple, and alternating. An important aspect of BM is that it is time sensitive; there is a predetermined amount of time in which the players' inputs are registered as being relevant. Though commonly seen, BM rarely exists in isolation; rather, it is often incorporated as a component in other challenges, such as reaction time challenges. The main examples of isolated button mashing come from games that are compilations of mini-games, or where the combat is turn based.

Note that it is important to differentiate between BM as a challenge and as a strategy. As a challenge, it is the intended play method, and the game must instruct the player to do so. As a strategy, it is predicated on the randomness of results from a barrage of inputs. We regard BM as a legitimate challenge, and will not further discuss it as a strategic choice.

**Single Input (SBM)** tasks the player with repeatedly pressing a specific button on the controller as fast as possible within a given time limit. An example is the "Manic Mallets" mini-game in *Mario Party 5* [27] where teams of two players must repeatedly hit a switch with a hammer to avoid being crushed by a bigger hammer. This mini-game lasts for only ten seconds, and success is solely dependent on the number of hammer hits executed during the time limit. Another example is *South Park: The Stick of Truth*'s "Dragon's Breath", a starting move for the mage class, where the player is informed to mash the A button in order to wave a lit firecracker in their op-

./Images/02-speed/ButtonMash-SouthPark-2.png

Figure 1: Dragon's Breath [44] - BM with implicit time limit

ponent's face (Figure 1) [44]. The game imposes an implicit time limit by syncing the button mashing with the length of the attack animation. In the *Bayonetta* series, "Torture Attacks" [49, 50] are similar, but also trigger cinematic animations that land the finishing blow to the enemy and increase the player's score.

**Alternating Input (ABM)** requires that players repeatedly press two specific buttons in sequence. The *Mario Party 2* mini-game "Psychic Safari" tasks players with powering up an ancient relic and destroying their opponent's relic within five seconds by alternately pressing the A and B button [24]. Similar are "Rockin' Raceway" (*Mario Party 3*) [25], "Slime Time" and "Take a Breather" (*Mario Party 4*) [26], as well as the speed skating events from the Nintendo DS version of *Mario and Sonic at the Winter Olympic Games*. All require the player to alternately mash the L and R shoulder buttons [54]. Cycling in *Mario and Sonic at the Olympic Games* for the Nintendo DS has the same controls (Figure 2) [53]. Alternating input also occurs paired with other BM challenges – in *Mario Party 3*'s "Ridiculous Relay", the three player team is tasked with performing various input patterns to complete their version of the relay race: an ABM segment, a learning combination moves segment, and a SBM segment all in succession [25].

**Multiple Input (MBM)** requires the player to push multiple buttons simultaneously and rapidly. One example is *Mario Party 2*'s "Mecha-Marathon" [24]; the players must *simultaneously* press the A and B buttons as quickly as they can within ten seconds. The number of times the player successfully presses both determines how far their wind-up doll will fly [24]. As with ABM, MBM is also found as a component of larger challenges. The *Mario Party 4* mini-game "Mario Medley" uses them alongside ABM [26]. We conjecture that MBM is less popular because of the difficulty in coordinating multiple simultaneous button presses. It can also explain why three button input is not used, as it would be too taxing on the player's cognitive and motor skills. Another possible reason for the unpopularity of MBM is the similarity in skills used in SBM, so that designers do not consider them to be different enough, and thus choose the cognitively simpler SBM instead.

./Images/02-speed/AlternatingInput-MarioAndSonicOlympic.png

Figure 2: Cycling [53] - images 0.5$s$ apart to show controls.

./Images/03-reaction-time/SimpleReaction-FFX.png

Figure 3: Tidus Overdrive, Swordplay [62]

### Reaction Time

Adams defines *reaction time challenges* (RTC) as testing the player's ability to react to events [2]. While all games require the player to react to stimuli, not all games feature RTCs. The difference is that these challenges **focus** on a player's reaction time. For example, while driving in Mario Kart requires that players react to their placement on the track as well as obstacles, it is not this activity that limits their ability to be competitive. RTCs are somewhat like speed challenges in that a time limit (usually implicit for RTCs) is present; however, speed challenges require no planning, while RTCs involve a perception-reaction loop. Specifically, the player must perceive an in-game event, understand what it means in their current context, plan an action which responds to this event, and execute that action. This entire process of perceive, plan, and react (*reaction processing loop*), is handled by the player in a matter of micro-seconds, allowing for a smooth gameplay experience. An important note is that memory plays a trivial to non-existent rôle in RTCs because the emphasis is on the reaction-processing loop. RTCs seem to be more abundant in contemporary games. They can be divided into three categories: simple, combat-based, and movement-based, with each having a variety of subcategories.

#### *Simple Reaction Time Challenges (SRT)*

SRT task the player to produce a specific input in response to a specific stimulus within a given time limit. An important aspect of RTCs is that they are isolated from normal gameplay, thereby allowing the player to focus entirely on the challenge. An example is Tidus' Overdrive, Swordplay, in *Final Fantasy X* [62], which presents the player with a countdown timer, a meter with a small coloured section in the centre, and the instructions to press "X" at the "right time!" (Figure 3). Likewise Quick Draw Corks from *Mario Party 2* provides both auditory and visual stimuli; the players are tasked with pressing the "A" button as soon as the Goomba says "GO!", with the fastest winning, and presses before the signal being penalized [24]. SRTs are not limited to single button presses — quick time events are also examples. These can range from pressing a single button (Quickenings in *Final Fantasy 12* [60]), mashing buttons (Joel's drowning sequence in *The Last of Us* [38]), wiggling thumbsticks (Leon shaking off a villager in *Resident Evil 4* [6]), to quickly moving controllers (escaping Raw Shocks in *Silent Hill: Shattered Mem-*

*ories*[9]). The time frames involved are all very similar. The variety of examples shows that the focus of SRTs is on taxing the player's attentional and perceptional abilities rather than their motor abilities.

### Advanced Combat Challenges (ACC)

We propose adding this new family to Adams' list of physical coordination challenges. It encompasses "learning complex combination moves", as well as a new class we call "attack chaining". They require the same basic set of skills (speed, timing, memory), albeit in different amounts, and the bottleneck on a player's performance seems to be motor abilities.

We must clearly define "combination moves" (*combos*) as the term is used differently in the community of players of *fighting* games. Adams explains combos as "an especially effective or spectacular attack [that would be executed if the player] could rapidly issue a particular sequence of buttons and joystick maneuvers" [2]. The fighting game community defines them as "a string of continuous moves that connect together with no time in between for the opponent to escape" [23]. That definition is not useful for our purposes; see instead "attack chaining" in the next section. Thus we modify Adams' definition as follows: combination moves are strings of input (length two or more) defined by the game to create a specific attack/ability. Notice that this definition does not say anything about whether the move can be blocked, countered, cancelled, evaded, or will result in stun-locking an opponent. In other words, "combination move" refers to the combination of inputs *only*. This then encompasses moves from the "light attack combo" in *Super Smash Bros.* (pressing the neutral attack button three times in quick succession) to the more complicated taunt move "Snake Charmer" by Squigly in *Skullgirls* (light punch, light punch, left, light kick, heavy punch).

**Attack Chaining (Chain)** is defined as "a series of player actions that are all successful. Success must be defined explicitly in game terms." [64]. We find this too broad, as it does not explicitly mention the combat context (other than in its name). We would replace "player actions" with "combat player actions" and include both offensive and defensive actions. These seem to only exist in games that have an intricate combat system. They often occur in games that also have (complex) combination moves, leading to confusion. For example, in *Super Smash Bros.* games, there are no combos, but players often chain independent moves to good effect.

## PLAYER ABILITIES

We explore the motor abilities through their interface to the player (controllers). We focus on: standard controllers (e.g. Xbox One and Playstation 4 controllers), handheld motion controllers (HMC) (e.g. Wii Remote, Playstation Move), full body motion controllers (e.g. Kinect), smartphones/tablet[1], handheld consoles (e.g. Nintendo 3DS, Playstation Vita), keyboards, mice, and fight sticks (arcade style controllers made for fighting games). We generate a list of possible interactions for each controller (e.g. press button, pull trigger, shake controller), making the assumption that most players are holding them in the ergonomically intended manner. We remove duplicate actions that are common between devices (e.g. pressing a key on a keyboard, and pressing a button on a standard controller) to arrive at the superset of interactions for the devices we examined. We then abstract from these interactions to the movement that drives it, so "pressing a button" becomes "pressing". We indicate whether these abilities are fine motor, gross motor, or both in Table 4. We further refine the list by attributing actions to body parts; we emphasize details for hands as they are currently the main mode of interaction.

[1]We will refer to them as "mobile" from here on.

| Motor Actions | Hardware Context | Type |
|---|---|---|
| Pressing | SC, HMC, HC, K, FS, M | Both |
| Bumping | SC, HC | Fine |
| Pulling | SC, HMC | Fine |
| Moving | SC, HMC, FBMC, HC, FS, mice | Both |
| Swiping | SC, mobile | Fine |
| Pinch-to-zoom | SC, mobile | Fine |
| Swinging | HMC | Both |
| Pointing | HMC | Both |
| Shaking | HMC, mobile, HC | Both |
| Drawing | HMC, mobile, HC | Both |
| Thrusting | HMC | Gross |
| Tilting | HMC, mobile, HC | Fine |
| Flicking | HMC, mobile | Both |
| Positioning | FBMC | Gross |
| Tapping | Mobile, HC | Fine |
| Speaking | Mobile, HC | Fine |
| MFC | HC | Fine |
| Clicking | Mice | Fine |
| Scrolling | Mice | Fine |

Table 4: Game actions, coloured for motor type (blue = fine, yellow = gross, green = both), and controllers.
SC = standard controller, HC = handheld console, FBMC = Full body motion controller, K = keyboard, FS = fight stick, M = mat controller

### Fine Motor Abilities

We group the fine motor actions from Table 4 by body part, and re-analyse the actions. While various body parts can perform the same motion, the context and results may differ.

#### *Fingers*

One approximation is that pressing, bumping, pulling, tapping, and clicking are the same action. Pressing is done by bending a finger or thumb at the knuckle to depress buttons on a controller; it is used on standard and handheld motion controllers, handheld consoles, keyboards, and fight sticks. Clicking is done by bending a finger to depress the button on a mouse; this is the same as pressing as the orientation of the fingers and wrist is similar. Thus we join them as the same action. Tapping is where players use their finger to touch a designated spot on a touchscreen; the motion used is identical, with an experiential difference due to the variance in feedback between touchscreens and physical buttons. As we want to isolate the motor abilities, we consider this difference as negligible and so group them together. Pulling is done by bending a finger to depress a trigger button; it is used in standard and HMCs. Like clicking, the only difference between pulling and pressing is the orientation of the player's hand, and so we again group them together. Bumping is done by bending a finger to depress the shoulder button on standard controllers and handheld consoles. The player's hand orientation matches pulling, as does the description so by the same logic we can group bumping with the others. Thus we encapsulate all of these actions under the name "Pressing".

Similarly swiping, flicking, and scrolling are the same action. Swiping is when a player moves their finger or a stylus across an area of a touch-sensitive surface; it is used with handheld consoles, and mobile. Flicking is the quick swiping across an area of a touch-sensitive surface; it exists on handheld consoles and mobile. The difference between flicking and swiping is time; flicking is a rapid action, while swiping can be done at any pace. As we are looking to coarsely define actions, certain time differences are negligible. We use Newell's Time Scale of Human Action to determine reasonably similar times. Newell outlines different "bands" (social, rational, cognitive, biological) which describes the order of magnitudes in which different actions happen [34]. The actions here all fall in the cognitive band (hundreds of milliseconds to tens of seconds), and so can reasonably be considered equivalent from a processing standpoint. Thus we join flicking and swiping. Scrolling is where the player bends their finger to rotate a scroll wheel, and is done with a mouse; "scrolling" on touchscreens is really swiping. While scrolling involves finger bending motions like pressing, the mechanics differ. Pressing is an entirely adductive movement (your finger is always moving inwards/towards your body), while scrolling is both abductive and adductive (you can move the scroll wheel towards or away from your body). Swiping is both abductive and adductive, and thus a closer fit to scrolling. Swiping and scrolling only differ in the choice of knuckle which bends; swiping motions tend to bend at the first knuckle (metacarpophalgeal joint – where the finger meets the hand), while scrolling tends to bend at the second or third knuckle. At our coarse level, there is no apparent effect on the time or experience of the motion due to this difference, so we group these actions together under the name "Swiping".

Pinch-to-zoom is the coordinated movement of two fingers to create a pincer-grip/pinching motion on a touch-sensitive surface, and is used on handheld consoles and mobile. It is independent due to its focus on motor coordination, which can be measurably more difficult for different age groups (performing coordinated activities has been shown to increase cognitive load for older adults [35, 56, 45, 33, 19]).

We distinguish between single task coordinated actions (STCA), like pinch-to-zoom, and multi-task coordinated actions (MTCA). STCAs require movement coordination to accomplish a single specified goal, while MTCAs involve two non-coordinated single task actions at the same time, for example controlling an avatar with the left thumbstick and the camera with the right. MTCAs, which are common, have an effect on the cognitive load (and thereby perceived difficulty) of the challenges, but may not affect the motor difficulty. This is because in MTCAs the level of motor difficulty is fixed (i.e. pressing a button has a fixed level of difficulty).

./Images/wristFlexExt.png

Figure 4: Wrist Flexion and Extension

*Wrist and Forearm*

At a first approximation, wrist movements are all the same, but with different speed requirements. This is due to the wrist being an ellipsoidal joint, offering a limited range of motion. Furthermore, when examining players' wrist motions, we notice that they also tend to move their forearms as well. Nevertheless, there seems to be enough in-game difference to keep some as separate actions.

Pointing is the controlled movement of the wrist (mainly) to position a cursor with a handheld controller. Wrist movements are limited to lateral (wrist flexion and extension Figure 4 — like waving as a greeting) and vertical (radial and ulnar deviation — like fanning oneself) due to how the controller is held. Occasionally players may use their forearms to increase their range of motion. Pointing is a continuous action; over extended periods of time, this is fatiguing and stressful, which will not concern us here.

Flicking is the quick lateral movement of the wrist used in moving a cursor with a HMC. However, flicking is discrete while pointing is a continuous action, affecting completion speed, and how and where these actions appear in a game. Pointing is used accuracy tasks (e.g archery Wii Sports Resort [42]) and can be a challenge on its own, as well as appear alongside pressing actions. Flicking exists as a supporting motion in many challenges; for example serving the ball in table tennis for Wii Sports Resort [42]. Since it is less accurate than pointing, flicking appears less frequently. Even though the underlying wrist movements are the same, this difference in game contexts merits keeping them separate.

Tilting involves moving entire controllers using coordinated wrist and forearm movements; it is used with HMCs, mobile, and handheld consoles. The way that each device is held affords different degrees of movement. For single-handed use of handheld controllers, tilting laterally involves wrist and forearm twisting to angle the controller in the same motion as turning a doorknob (wrist supination and pronation Figure

./Images/wristSupPro.png

Figure 5: Wrist Supination and Pronation

./Images/forearmFlexExt.png

Figure 6: Forearm flexion and extension

5). Tilting vertically is the same movement as vertical pointing movements (radial and ulnar deviation). For mobiles held in a single hand in portrait mode, tilting is the same as for HMCs. In comparison, HMCs held horizontally, mobiles in landscape mode and handheld consoles are held between the hands; tilting up and down, the motion remains the same as vertical tilting for HMCs (radial and ulnar deviation). When tilting laterally, the wrist's main function is stability and the tilting motion is performed by coordinated movement of the forearms (forearm flexion and extension Figure 6). For example, when holding the Nintendo Wii U gamepad, tilting the device laterally to the left requires the player's right forearm to move up (flexion) while their left forearm simultaneously moves downward (extension). The player's wrists remain stable in order to hold the controller so it is not dropped. An example is steering the flying beetle item in The Legend of Zelda: Skyward Sword [39] Tilting is a continuous action, like pointing, but the additional twisting movement is a sufficient difference to keep them separate. Drawing is the interaction of moving a brush proxy in a controlled path over a canvas using predominantly wrist and forearm movements. It is used with: HMCs (held in a single hand), which act as a brush proxy to paint in the air (canvas); mobile, and handheld consoles, where the brush proxy is either a finger or a stylus used to paint on a touchscreen (canvas). Drawing predominantly uses wrist motions, taking advantage of its lateral, vertical, and rotational movements; forearm movements may be incorporated for larger canvases (that surpass wrist range) — which makes it distinct from the previous two actions.

Swinging is the repeated lateral movement of the wrist using a HMCs held in a single hand. Examples include using the fishing rod and net in Animal Crossing: City Folk [41], cracking an egg in Cooking Mama: Cook Off [11], and sword actions in The Legend of Zelda: Skyward Sword [39]. A minimum of two distinct lateral wrist movement occur (back and forth), though more can be used to repeat the in-game actions. The difference between swinging and flicking is their speed; flicking is fast and less precise, while swinging can be steady and accurate. These differences distinguish these actions.

Shaking is the quick repetitive movements of the wrist and/or forearm to move a controller; it exists, in the context of HMCs

./Images/forearmRotation.png

Figure 7: Forearm flexion and extension while holding a HMC

(both orientations), mobile, standard controllers, and handheld consoles. For HMCs held in one hand and mobiles in portrait mode, shaking exists as either a vertical wrist motion (radial and ulnar deviation) mimicking the motion of a drumstick tapping on a drum, or as a jerking forearm movement (forearm rotation Figure 7) similar to the motion of shaking a cocktail shaker. Examples include: ground pound in Donkey Kong Country Returns when using a HMC [51], and asteroid in SpaceTeam on mobile [58]. For HMCs held horizontally, mobiles in landscape mode, standard controllers, and handheld consoles (which are held between the hands), shaking is exclusively the result of forearm movement (forearm flexion and extension). Though shaking actions are possible for all these controllers in this orientation, they are most common for HMCs. Examples include: ground pound in Donkey Kong Country: Tropical Freeze [52], performing wheelies in Mario Kart 8 [40], and performing the homing hat throw in Super Mario Odyssey [43]. We were unable to find examples of shaking for landscape mobile and handheld consoles. This is possibly because these have the screen attached, so shaking the controls shakes the screen too, making the game extremely difficult to play. The movements for all shaking contexts are sufficiently different to remain separate.

### *Neck and Face*

Head movements such as tilting, nodding and shaking are done by moving the neck. These actions are becoming more important for AR and VR games, which use headsets and monitor head movements as input – but out of scope.

A face's actions are: making expressions and speaking. Facial expressions can be seen by the front camera of handheld consoles (e.g. Pokemon Amie Pokemon X and Y [17, 18]). Speaking as an action exists for mobiles, and handheld consoles, using the device's microphone. Speaking does not imply natural language processing, rather the microphone is only used to detect whether a noise is made and at what intensity. Examples include Puzzle 138 in Professor Layton and the Diabolical Box, which requires players to blow into their microphone simulating a gust of wind [32], and Chicken Scream on mobile which allows the user to control how the chicken avatar moves by making sounds [48].

### *Ankle and Feet*

Existing controllers that use foot input (mat controllers) only allow for pressing. Even though there are many potential movements for ankles and feet, we consider the two as a single unit and condense all actions to just "pressing". Examples include Dance Dance Revolution [30], Shaun White Skateboarding [65], and Mario and Sonic at the Winter Olympic Games [55].

In short, the **distinct** fine motor abilities are given in Table 5.

## RELATING CHALLENGES AND ABILITIES

We picked four different instances for each challenge (e.g. different genres, platforms, controllers) to show that these are not genre- or platform-dependent. We have included visual summaries of these analyses, colour-coded and labeled with abbreviations for the different abilities: **A**ttention (purple), **P**erception (green), **M**emory (yellow), **F**inger **P**ressing

| | | |
|---|---|---|
| Hands | Fingers | Pressing<br>Swiping<br>Pinching |
| | Wrist | Shaking<br>Flicking<br>Pointing<br>Swinging<br>Drawing<br>Tilting |
| Head | Neck | Moving |
| | Face | Speaking<br>Making facial expressions |
| Feet | Ankle and Foot | Pressing |

Table 5: Fine motor actions divided by body parts

./Images/analysis-SIBM-1.png

Figure 8: SBM analysis with error bars of ±10

(blue), **F**inger s**w**iping (dark blue), **F**orearm **S**haking (pink), **W**rist **P**ointing (orange), and generic **M**otor **A**bility (red).

### Speed: Button Mashing

*Single Input (SBM)*

| Game Instance | Control. | Motor | Cog. |
|---|---|---|---|
| Manic Mallets [27] | Std | FP, WP | P |
| Dragon's Breath [44] | Mouse | FP, WP | P |
| Boss Knockouts [52] | HM horz. | FP, WP | P |
| Holding breath in fight [31] | Std | FP, wrist tilt., FS | A, P |

Motor abilities are the focus of this challenge. Finger pressing is the limiting factor (L), as it was to be most important regardless of context (absolute difficulty, single vs. multiplayer, chance of loss/game over, etc). In relation to finger pressing, wrist pointing is noticeably used (N) but would not ever impede a player from winning. These motions are a natural consequence of how the player holds the controller, with their finger resting on buttons. Wrist/forearm shaking is noticeably used (N) as it becomes more important as the difficulty of the challenge increases. Between wrist/forearm shaking and wrist pointing we believe that the former is more important during play. Regardless of context, perception and attention were both used (equally), but not important (U).

*Alternating Input (ABM)*

The limiting factor is again the player's motor abilities, specifically finger pressing (L). Wrist pointing and attention are noticeably used (N), as both played an identifiable role but not enough to deter winning. Wrist pointing was important in relation to finger pressing, as we felt that we were able to press the buttons faster with wrists locked rather than loose. Attention was important for rhythm, as if we got out of sync (i.e. pressing the same button twice) it would throw off the whole score. Perception was used, but not important (U).

*Multiple Input (MBM)*

Here too the limiting factor is motor abilities, especially finger pressing, regardless of controller used. Wrist/forearm tilting is important, but not limiting (I), however it did become the dominant motion as the challenge became harder. Attention (for motor coordination) and wrist pointing were both noticeably used (N). Perception was used, but not important (U).

### Reaction Time: Simple Reaction Time (SRT)

| Game Instance | Control. | Motor | Cog. |
|---|---|---|---|
| Quickenings [60] | Std | FP | P, A |
| Shaking off villager [6] | Std | FW | P, A |
| Escaping Raw Shocks [9] | HM-vert. | FS, Arms | P, A |
| Up for Grabs [28] | HC (DS) | Wrist tilt, FP | P, A |

Table 6: Simple reaction time

By comparison, SRT appear to principally tax a player's cognitive abilities. Indeed, many motor skills can be used for SRT (Table 6). However SRT all strain a player's perceptional and attentional abilities. SRT is about simple actions needing to be performed quickly and without warning. As such, the hardware and player contexts are irrelevant in terms of difficulty or importance. Thus we list the generic motor ability at noticeably used (N). It is hard to tell whether perception or attention is more taxed in this challenge (a controlled experiment would be needed); here we assume they take equal effort. Perception is the obvious limiting factor (L). Attention is important, but not limiting (I), although it could become limiting for SRTs over an extended period of time.

### Advanced Combat: Attack Chaining

| Game Instance | Control. | Motor | Cog. |
|---|---|---|---|
| Combat in Smash [4] | HC | FP, FW | M, P, A |
| Combat in BDO [47] | K & M | FP, FW | M, P, A |
| Combat in KH2 [61] | Std | FP, FW | M, P, A |
| Combat in Brawl [20] | HM horz. | FP, FW | M, P, A |

Table 7: Attack Chaining

This challenge relies exclusively on buttons (finger pressing) and thumbsticks (finger swiping) — even for touchscreen inputs we find that the game provides on screen controls to

./Images/analysis-AIB-1.png

Figure 9: ABM analysis with error bars of ±10

./Images/analysis-MIBM-1.png

Figure 10: MBM analysis with error bars of $\pm 10$

mimic a controller. Controls with motion capabilities nevertheless favour button and thumbstick inputs over larger motions. This is likely because combat is meant to be fast, and only finger pressing & swiping offer that feeling. As executing continuous strings of input is the focus of this challenge, it is stresses motor abilities, and in particular finger pressing is the limiting factor (L). Direction input (via wrist or finger movement) is important but not limiting (I).

Memory is used (U) to remember attack execution and basic information about how attacks combine. This may become more important for high level play once strategy, stunlocking, and mechanics exploitation comes into play.

The reactionary nature of fluid combat make perception and attention important (I). With attack chaining, the player needs to not only be able to perform the various combinations, but also to read and react to what their opponent is doing. As with motor abilities, it is difficult to separate which of these cognitive abilities is more important. We place perception above attention to account for the fact that perception marks the beginning of the reaction processing loop.

## DISCUSSION

### Applications

We see our work being useful for analysing existing games and developing new games from the perspective of differently-abled players. By giving designers a means to discuss the impact of player abilities on challenge completion, we provide the opportunity for design-time adjustments towards more mechanically inclusive play. Similarly, we give designers and academics a joint framework to discuss existing games for specific playability issues from player perspectives, and a way to discuss solutions for different groups.

We also see this framework as pointing out unexplored parts of the design space of challenges — and thus the potential to create novel gameplay experiences. By comparing challenge-ability configurations, we can get a picture of what abilities are being underused. Such insight can give designers opportunities to create new mechanics. Similarly, novel gameplay can be systematically created for different controller contexts. For example, with a camera, facial expressions can be used in a reaction time context, à la "Simon Says" where the

./Images/analysis-SRT-1.png

Figure 11: SRT analysis with error bars of $\pm 10$

./Images/analysis-AC-1.png

Figure 12: AC analysis with error bars of $\pm 10$

player must quickly match an expression. Another design avenue is creating gross motor equivalents to exclusively fine motor challenges; for example, rapid shape drawing could be adapted for gross motor abilities by having players make shapes with their arms (or whole bodies) instead of drawing them.

### Improvements

We know of two issues with our methodology. First, outlier examples, which are instances of a particular challenge whose ability configuration are drastically different than the rest of their siblings. These seem to occur when a particular challenge exists across vastly different control schemes; for example, *Rapid Shape Drawing* can be found on mobiles (e.g. Do or Dry [29]), handheld consoles (e.g. Wash Rice [10]), and HMCs (e.g. Healing Touch [3]). If players use their finger as a drawing tool (mobiles, handheld consoles) they would often choose to either rotate their finger at the knuckle or to keep it steady and use their wrist; players using a stylus on their touchscreen (mobiles, handheld consoles) can use just wrist motions; for a HMC, the action would require either wrist or shoulder movements. We have recorded these outlier instances in our analyses, but have focused on the most common ability configurations. The existence of outliers suggests a need to further refine the list of challenges, given that our definition states that a challenge has a particular ability configuration.

Secondly, our data comes from observing a small number of people (i.e. not statistically significant); this gives general insight, which we nevertheless believe to be "generally right", as we can come up with post facto rational explanations based on existing HCI, DevPsy and cognitive psychology theories. We also need to isolate different abilities to better understand their relevance to given challenges. In other words, we should some controlled experiments to verify the claims of our theory, and isolate the effect of different abilities.

### Future Work

We are already working on refining and extending this framework. We are pursuing three routes: improving the analysis through running experiments; expanding the player model with a more descriptive cognitive model; and, expanding the challenges model to include more challenge types. We are also planning to explore the impacts of longer play sessions on the motor experience through via fatigue and repetitive stress, and the cognitive experience impact of high cognitive load challenges.

## CONCLUSION

Our framework was designed to further understand the challenge-abilities relations of the game-player system, focusing on psycho-motor and lower level cognitive abilities — in other words, the "mechanical human". We systematically explored certain kinds of challenges, and human lower cognitive and motor abilities. This exploration yielded 18 distinct challenges, and 21 motor abilities (13 fine motor and 8 gross motor), a selection of which were outlined here. We then revisited the challenges to determine which motor abilities are used to complete them, and how important each was to completion. We believe that this can be fruitfully used to analyse existing games and develop new games for players with differing abilities; as well as being helpful for creating novel gameplay experiences out of under-used abilities.

## REFERENCES


1. Edwin A. Fleishman, Marilyn K. Quaintance, and Laurie A. Broedling. 1984. *Taxonomies of Human Performance: The Description of Human Tasks*. Academic Press, San Diego, CA, USA.
2. Ernest Adams. 2010. *Fundamentals of Game Design* (2 ed.). New Riders, Berkley, CA, USA.
3. Atlus. 2006. *Trauma Center: Second Opinion*. Game [Wii]. (19 November 2006). Atlus USA, California, USA.
4. Bandai Namco Games, Sora Ltd, and tri-Crescendo. 2014. *Super Smash Bros. for Nintendo 3DS*. Game [3DS]. (3 October 2014). Nintendo, Kyoto, Japan.
5. Staffan Bjork and Jussi Holopainen. 2004. *Patterns in game design (game development series)*. Charles River Media, Needham Heights, MA, USA.
6. Capcom Production. 2005. *Resident Evil 4*. Game [Gamecube]. (11 January 2005). Capcom, Osaka, Japan.
7. Stuart K. Card, Allen Newell, and Thomas P. Moran. 1983. *The Psychology of Human-Computer Interaction*. L. Erlbaum Associates Inc., Hillsdale, NJ, USA.
8. Jenova Chen. 2007. Flow in Games (and Everything else). *Commun. ACM* 50, 4 (April 2007), 31–34. DOI: http://dx.doi.org/10.1145/1232743.1232769
9. Climax Studios. 2009. *Silent Hill: Shattered Memories*. Game [Wii]. (8 December 2009). Konami, Tokyo, Japan.
10. Cooking Mama Ltd. 2006. *Cooking Mama*. Game [Nintendo DS]. (12 September 2006). Majesco Entertainment, New Jersey, USA.
11. Cooking Mama Ltd. 2007. *Cooking Mama: Cook Off*. Game [Wii]. (20 March 2007). Majesco Entertainment, New Jersey, USA.
12. Mihaly Csikszentmihalyi. 1997. *Finding flow: The psychology of engagement with everyday life.* Basic Books, New York, NY, USA.
13. Damien Djaouti, Julian Alvarez, Jean-Pierre Jessel, Gilles Methel, and Pierre Molinier. 2008. A gameplay definition through videogame classification. *International Journal of Computer Games Technology* 2008 (2008), 4.
14. M.W. Eysenck and M.T. Keane. 2010. *Cognitive Psychology: A Student's Handbook* (6 ed.). Psychology Press, New York, NY, USA.
15. John Feil and Marc Scattergood. 2005. *Beginning game level design*. Thomson Course Technology, Boston, MA, USA.
16. Kathleen M Galotti. 2015. *Cognitive development: Infancy through adolescence* (2 ed.). Sage Publications, Thousand Oaks, CA, USA.
17. Game Freak. 2013a. *Pokemon X*. Game [3DS]. (12 October 2013). Nintendo, Kyoto, Japan.
18. Game Freak. 2013b. *Pokemon Y*. Game [3DS]. (12 October 2013). Nintendo, Kyoto, Japan.
19. Ben Godde and Claudia Voelcker-Rehage. 2017. Cognitive Resources Necessary for Motor Control in Older Adults Are Reduced by Walking and Coordination Training. *Frontiers in Human Neuroscience* 11 (2017), 156. DOI: http://dx.doi.org/10.3389/fnhum.2017.00156
20. HAL Laboratory, Inc., Intelligent Systems, Sora Ltd, Game Arts, Monolith Soft, and Paon. 2008. *Super Smash Bros. Brawl*. Game [Wii]. (9 March 2008). Nintendo, Kyoto, Japan.
21. Juho Hamari and Janne Tuunanen. 2014. Player types: a meta-synthesis. *Transactions of the Digital Games Research Association* 1, 2 (2014), 29–53. DOI: http://dx.doi.org/10.26503/todigra.v1i2.13
22. N Hamilton, W Weimar, and K Luttgens. 2012. *Kinesiology: Scientific basis of human motion* (12 ed.). McGraw-Hill, New York, NY, USA.
23. Patrick Hancock. 2012. A quick guide to popular fighting game people and jargon. (Jul 2012). https://www.destructoid.com/a-quick-guide-to-popular-fighting-game-people-and-jargon-230779.phtml
24. Hudson Soft. 2000. *Mario Party 2*. Game [N64]. (24 January 2000). Nintendo, Kyoto, Japan.
25. Hudson Soft. 2001. *Mario Party 3*. Game [N64]. (7 May 2001). Nintendo, Kyoto, Japan.
26. Hudson Soft. 2002. *Mario Party 4*. Game [Gamecube]. (8 November 2002). Nintendo, Kyoto, Japan.
27. Hudson Soft. 2003. *Mario Party 5*. Game [Gamecube]. (10 November 2003). Nintendo, Kyoto, Japan.
28. Intelligent Systems and Nintendo SPD. 2005. *WarioWare: Touched!* Game [DS]. (14 February 2005). Nintendo, Kyoto, Japan.
29. Julian Frost and Samuel Baird. 2013. *Dumb Ways to Die*. Game [Android]. (17 September 2013). PopReach, Ontario, Canada.
30. Konami. 1999. *Dance Dance Revolution*. Game [Arcade]. (March 1999). Konami, Tokyo, Japan.

31. Konami Computer Entertainment Japan. 2001. *Metal Gear Solid 2: Sons of Liberty*. Game [PS2]. (12 November 2001). Konami, Tokyo, Japan.
32. Level-5. 2009. *Professor Layton and the Diabolical Box*. Game [DS]. (24 August 2009). Nintendo, Kyoto, Japan.
33. Ulman Lindenberger, Michael Marsiske, and Paul B Baltes. 2000. Memorizing while walking: increase in dual-task costs from young adulthood to old age. *Psychology and aging* 15, 3 (2000), 417.
34. I. Scott MacKenzie. 2013. *Human-Computer Interaction: An Empirical Research Perspective* (1st ed.). Morgan Kaufmann Publishers Inc., San Francisco, CA, USA.
35. BR Malcolm, JJ Foxe, JS Butler, and P De Sanctis. 2015. The aging brain shows less flexible reallocation of cognitive resources during dual-task walking: A mobile brain/body imaging (MoBI) study. *NeuroImage* 117 (2015), 230.
36. Thomas W. Malone. 1980. What Makes Things Fun to Learn? Heuristics for Designing Instructional Computer Games. In *Proceedings of the 3rd ACM SIGSMALL Symposium and the First SIGPC Symposium on Small Systems (SIGSMALL '80)*. ACM, New York, NY, USA, 162–169. DOI:http://dx.doi.org/10.1145/800088.802839
37. Nicole McMahon, Peta Wyeth, and Daniel Johnson. 2015. From Challenges to Activities: Categories of Play in Videogames. In *Proceedings of the 2015 Annual Symposium on Computer-Human Interaction in Play (CHI PLAY '15)*. ACM, New York, NY, USA, 637–642. DOI:http://dx.doi.org/10.1145/2793107.2810333
38. Naughty Dog. 2013. *The Last of Us*. Game [PS4]. (14 June 2013). Sony Computer Entertainment, California, USA.
39. Nintendo EAD. 2011. *The Legend of Zelda: Skyward Sword*. Game [Wii]. (20 November 2011). Nintendo, Kyoto, Japan.
40. Nintendo EAD. 2014. *Mario Kart 8*. Game [WiiU]. (30 May 2014). Nintendo, Kyoto, Japan.
41. Nintendo EAD Group No. 2. 2008. *Animal Crossing: City Folk*. Game [Wii]. (17 November 2008). Nintendo, Kyoto, Japan.
42. Nintendo EAD Group No. 2. 2009. *Wii Sports Resort*. Game [Wii]. (26 July 2009). Nintendo, Kyoto, Japan.
43. Nintendo EPD. 2017. *Super Mario Odyssey*. Game [Switch]. (27 October 2017). Nintendo, Kyoto, Japan.
44. Obsidian Entertainment and South Park Digital Studios. 2014. *South Park: The Stick of Truth*. Game [Xbox]. (4 March 2014). Ubisoft, Rennes, France.
45. Selma Papegaaij, Wolfgang Taube, Stéphane Baudry, Egbert Otten, and Tibor Hortobágyi. 2014. Aging causes a reorganization of cortical and spinal control of posture. *Frontiers in Aging Neuroscience* 6 (2014), 28. DOI: http://dx.doi.org/10.3389/fnagi.2014.00028
46. V. Gregory Payne and Larry David Isaacs. 2012. *Human motor development: a lifespan approach* (8 ed.). McGraw-Hill, New York, NY, USA.
47. Pearl Abyss. 2016. *Black Desert Online*. Game [PC]. (3 March 2016). Kakao Games, Jeju, South Korea.
48. Perfect Tap Games. 2017. *Chicken Scream*. Game [Android]. (28 April 2017). Perfect Tap Games, Dubai, UAE.
49. Platinum Games. 2010. *Bayonetta*. Game [Xbox 360]. (5 January 2010). Sega, Tokyo, Japan.
50. Platinum Games. 2014. *Bayonetta*. Game [WiiU]. (24 October 2014). Nintendo, Kyoto, Japan.
51. Retro Studios. 2010. *Donkey Kong Country: Returns*. Game [Wii]. (21 November 2010). Nintendo, Kyoto, Japan.
52. Retro Studios. 2014. *Donkey Kong Country: Tropical Freeze*. Game [WiiU]. (21 February 2014). Nintendo, Kyoto, Japan.
53. Sega Sports R&D. 2008. *Mario and Sonic at the Olympic Games*. Game [DS]. (22 January 2008). Sega, Tokyo, Japan.
54. Sega Sports R&D and Racjin. 2009a. *Mario and Sonic at the London 2012 Olympic Games*. Game [DS]. (13 October 2009). Sega, Tokyo, Japan.
55. Sega Sports R&D and Racjin. 2009b. *Mario and Sonic at the London 2012 Olympic Games*. Game [Wii]. (13 October 2009). Sega, Tokyo, Japan.
56. Rachael D Seidler, Jessica A Bernard, Taritonye B Burutolu, Brett W Fling, Mark T Gordon, Joseph T Gwin, Youngbin Kwak, and David B Lipps. 2010. Motor control and aging: links to age-related brain structural, functional, and biochemical effects. *Neuroscience & Biobehavioral Reviews* 34, 5 (2010), 721–733.
57. David R Shaffer and Katherine Kipp. 2010. *Developmental psychology: Childhood and adolescence* (8 ed.). Cengage Learning, Boston, MA, USA.
58. Sleeping Beast Games. 2012. *Spaceteam*. Game [Android]. (1 December 2012). Sleeping Beast Games, Montreal, Canada.
59. Sasha M Soraine. 2019. *Ooh What's This Button Do?* Master's thesis. McMaster University. http://hdl.handle.net/11375/24028
60. Square Enix. 2006. *Final Fantasy XII*. Game [PS2]. (31 October 2006). Square Enix, Tokyo, Japan.
61. Square Enix Product Development Division 1. 2006. *Kingdom Hearts 2*. Game [PS2]. (28 March 2006). Square Enix, Tokyo, Japan.
62. Square Product and Development Division 1. 2001. *Final Fantasy X*. Game [PS2]. (17 December 2001). Square Electronic Arts, California, USA.

63. Penelope Sweetser and Peta Wyeth. 2005. GameFlow: A Model for Evaluating Player Enjoyment in Games. *Comput. Entertain.* 3, 3 (July 2005), 3–3. DOI: http://dx.doi.org/10.1145/1077246.1077253

64. Richard Terrell. 2014. The Design of Combos and Chains. (2014).

65. Ubisoft Montreal. 2010. *Shaun White Skateboarding*. Game [Wii]. (24 October 2010). Ubisoft, Rennes, France.

66. Cinnamon VanPutte, Jennifer Regan, and Andrew Russo. 2011. *Seeley's Anatomy and Physiology* (9 ed.). McGraw-Hill, New York, NY, USA.

67. Karhulahti Veli-Matti. 2014. Puzzle Is Not a Game! Basic Structures of Challenge. In *Proceedings of the 2013 DiGRA International Conference: DeFragging Game Studies*. DiGRA. http://www.digra.org/wp-content/uploads/digital-library/paper_179.pdf

68. Wayne Weiten. 2007. *Psychology: Themes and variations: Themes and variations*. Cengage Learning, Boston, MA, USA.

69. Tian Zhu, Bingtang Wang, and Michael Zyda. 2018. Exploring the Similarity Between Game Events for Game Level Analysis and Generation. In *Proceedings of the 13th International Conference on the Foundations of Digital Games (FDG '18)*. ACM, New York, NY, USA, Article 8, 7 pages. DOI: http://dx.doi.org/10.1145/3235765.3235804